West Offaly Power

Thermal Discharge Synthesis Report

Document No.: QS-000152-01-R402-000

Jointly Prepared by ESB International and Aquatic Services Unit

Date: February 2018

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File Reference:	QS-000152	
Client / Recipient:	ESB Generation and Wholesale Markets	
Project Title:	West Offaly Power Thermal Discharges	
Report Title:	West Offaly Power Thermal Discharge Synthesis Report	
Report No.:	QS-000152-01-R402-000	
Revision No.:		
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Template Used: T-020-007-ESBI Report Template

Change History of Report

Date	New Revision	Author	Summary of Change

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1 Introduction

1.1 West Offaly Power

West Offaly Power Generating Station (WOP) is located adjacent to the River Shannon at Shannonbridge County Offaly. See Figure 1-1. The station is a peat fired base load station i.e. continuous operation, subject to availability. The installed capacity is 150MWe and the station was commissioned in 2005. The milled peat-fired boiler generates steam which is used to drive turbines which produce electricity. The steam is then cooled to hot water and recirculated to the boiler. The steam is cooled by water abstracted from and returned to the River Shannon.

The aqueous principal discharge from the power station is cooling water discharge. The station discharges approximately 186MWth to the river Shannon when on full load. This consists of a flow through the condenser of 5.5 m^3/s with a temperature rise of approximately 8˚C. The flow through the condenser will vary slightly depending on the level of the River Shannon with a corresponding variation in the rise in temperature.

There has been continuous production of electricity at Shannonbridge since 1965 when a 40 MWe unit was commissioned. The station was extended in 1977 and again in 1982. The installed capacity in 1982 was 125MWe and this discharged a thermal load to the River Shannon of approximately 260MWth. This consisted of a flow through the condenser of 7.7m^3/s with an 8˚C temperature rise and all units on full load. This station was decommissioned in 2003 and its associated Integrated Pollution Control Licence (No. P0626-01) was surrendered in 2011.

Figure 1-1: General Location of West Offaly Power at Shannonbridge

West Offaly Power Generating Station operates within the framework of Environmental Protection Agency (EPA) Industrial Emissions Licence (IEL) (No. P0611-02). Condition 5.5 of the Licence concerns the thermal discharge from the station and states that:

Discharges from the installation shall not artificially increase the ambient temperature of the receiving water by more than 1.5 °C outside the mixing zone. In relation to temperature, the mixing zone shall not exceed 25% of the cross sectional area of the river at any point.

A Licence Review was completed in September 2013. Condition 5.5 was amended to include the requirement that the mixing zone should not exceed 25% of the cross sectional area of the river. Prior to this no defined footprint of the mixing zone was specified and the requirement in the licence (P0611-01) under Condition 6.11 was that:

No effluent shall be discharged which results in a temperature increase at the edge of the mixing zone of greater than 1.5^{o}C in the receiving system.

In addition, Condition 5.1 of the Licence states that:

No specified emission from the installation shall exceed the emission limit values set out in Schedule B: Emission limits, of this licence. There shall be no other emissions of environmental significance.

1.2 Scope of Report

ESB Generation and Wholesale Markets commissioned ESB International (ESBI) and Aquatic Services Unit from UCC to undertake a series of surveys and studies of the effects of the thermal discharges from West Offaly Power Generating Station on its receiving waters. These surveys and studies include:

- Four thermal plume surveys at West Offaly Power undertaken by Irish Hydrodata between July 2014 and May 2016.
- Programme of continuous temperature monitoring undertaken by Irish Hydrodata at a number of fixed points in the Shannon at Shannonbridge from August 2016.
- Three surveys at Shannonbridge close to West Offaly Power Station (WOP) were undertaken by Aquatic Services Unit in 2014, 2015 and 2016 which covered diatoms, macrophytes and macroinvertebrates
- Five fyke net surveys at Shannonbridge undertaken by Denis Doherty (ESB Fisheries) and his team in August 2016, October 2016, February 2017, November 2017 and December 2017.
- Literature Review of Potential Fisheries Impacts. Aquatic Services Unit July 2016

This synthesis report draws together and summarises the results of these surveys and studies for West Offaly Power. It also considers compliance with Condition 5.5 of the relevant Industrial Emissions Licence associated with each station.

1.3 Thermal Plumes

Thermal plumes have a complex physical structure. They are less dense than the receiving waters into which they flow because of their higher temperature. This causes the cooling water to flow over the surface of the ambient water and the increase in temperature to be confined to the surface. The depth of the thermal plume is not constant. The maximum depth of the thermal plume occurs at the discharge point and decreases with distance away from the discharge point. The gradient between the thermal plume and receiving waters is sharp in the vertical direction and sudden variations in temperature of 6 °C can occur over a distance of 1-2 m below the surface. The gradients are considerably less in the horizontal direction.

The main factors which affect the thermal plume are:

- The quantity of heat discharged into the receiving waters.
- The maximum thermal load discharged occurs when the station is on full load.
- River flow.
- Meteorological conditions.
- Bathymetry and
- Vegetation

2 Environmental Setting

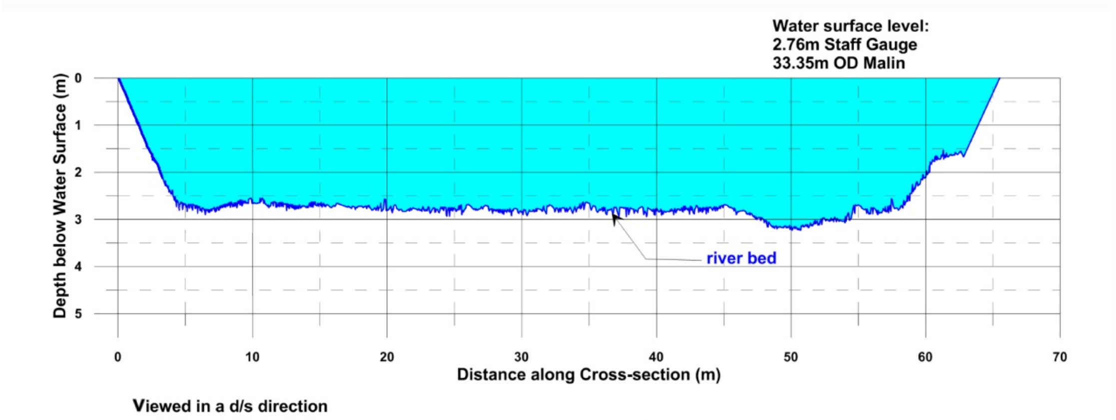
2.1 Cooling water discharge

The thermal cooling water discharge from West Offaly Power occurs just upstream of the Bord na Mona railway Bridge at Shannonbridge and on the left bank of the river Shannon. The abstraction point is sited approximately 190 m upstream of the discharge location.

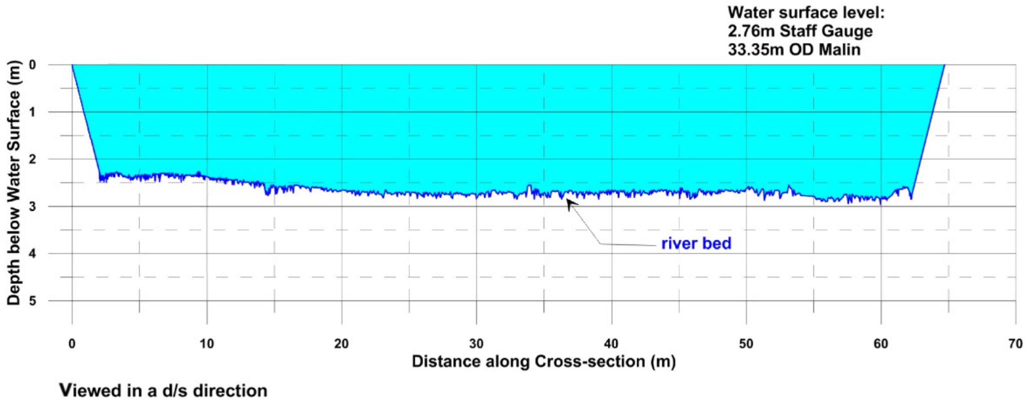
The cooling water consists of a flow through the condenser of 5.5 m^3/s which is subject to a temperature rise of approximately 8°C. The flow through the condenser can vary slightly depending on the level of the River Shannon but load will vary with a corresponding variation in the rise in temperature.

Figure 2-1: West Offaly Power at Shannonbridge

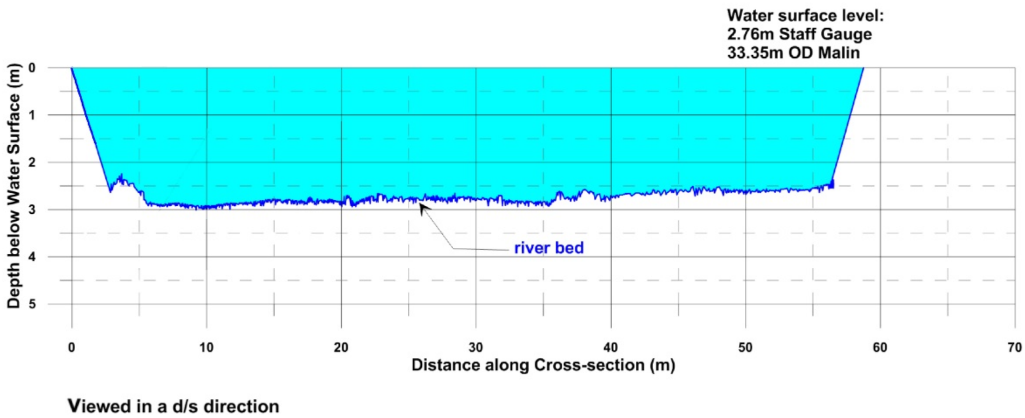
Figure 2-2 below illustrates typical cross-sections of the River Shannon downstream of the WOP outfall as surveyed by Irish Hydrodata in 2015. The cross-section locations are indicated in Figure 2-3



Cross-section at 75m d/s of bridge



Cross-section at 250m d/s of bridge



Cross-section at 425m d/s of bridge

Figure 2-2 River Shannon cross-sections at Shannonbridge

Figure 2-3 illustrates the locations of the cross-sections presented in Figure 2-2.

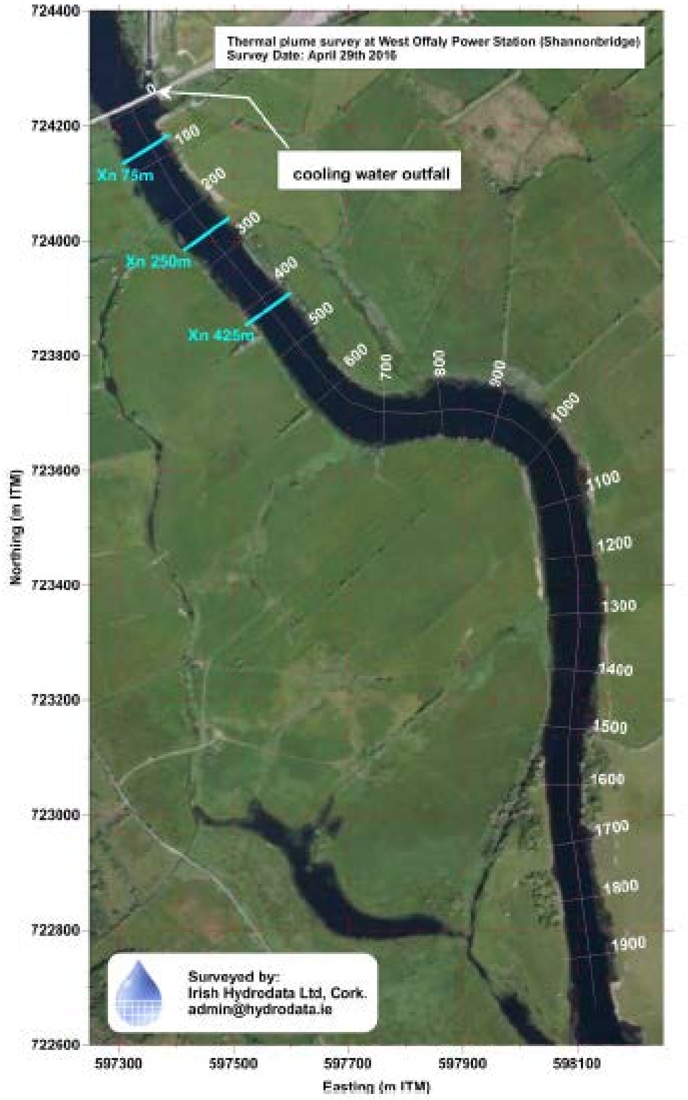


Figure 2-3 Location of River Shannon cross-sections at Shannonbridge (IHD)

2.2 Hydrology

In order to assess the impact of the thermal discharge from West Offaly Power on the River Shannon, consideration of the flows in the River Shannon is required.

There are a number of hydrometric gauging stations on the River Shannon operated by ESB, the Office of Public Works (OPW) and local authorities. These gauges are used to record water levels in the River Shannon. At certain locations, series of flow measurements have been taken and a relationship between water level and flow (known as a rating curve) developed.

Table 2-1 below gives details of hydrometric gauges of particular relevance for West Offaly Power Generating Station. The gauge locations are illustrated in Figure 2-4.

Station No	Location	Data Source	Catchment Area upstream km²	Easting	Northing
26028	Shannonbridge	OPW	4,969	196707	225451
26027	Athlone	ESB	4,601	204042	241293
25017	Banagher	OPW	7,981	200506	215829
26007	Belagill (Suck)	OPW	1,207	184175	234570

Table 2-1: Selected River Shannon Hydrometric Gauges (WOP)

As noted in Table 2-1, there is a water level gauge located on the Shannon at Shannonbridge upstream of West Offaly Power Station. The EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26028) at Shannonbridge as a reference indicator of flow conditions in the Shannon at West Offaly Power. The records of water level at Shannonbridge are available from the OPW website www.waterlevel.ie. (The notes and warnings concerning the source, reliability and use of the data available on this website as set out in http://waterlevel.ie/disclaimer/ are fully acknowledged.) The gauge at Shannonbridge is not rated and therefore, flow records are not available.

Shannonbridge gauge is sited upstream of the Suck confluence whereas the cooling water discharge from West Offaly Power is downstream of the confluence. The catchment area to the cooling water discharge point is approximately 6,200 km².

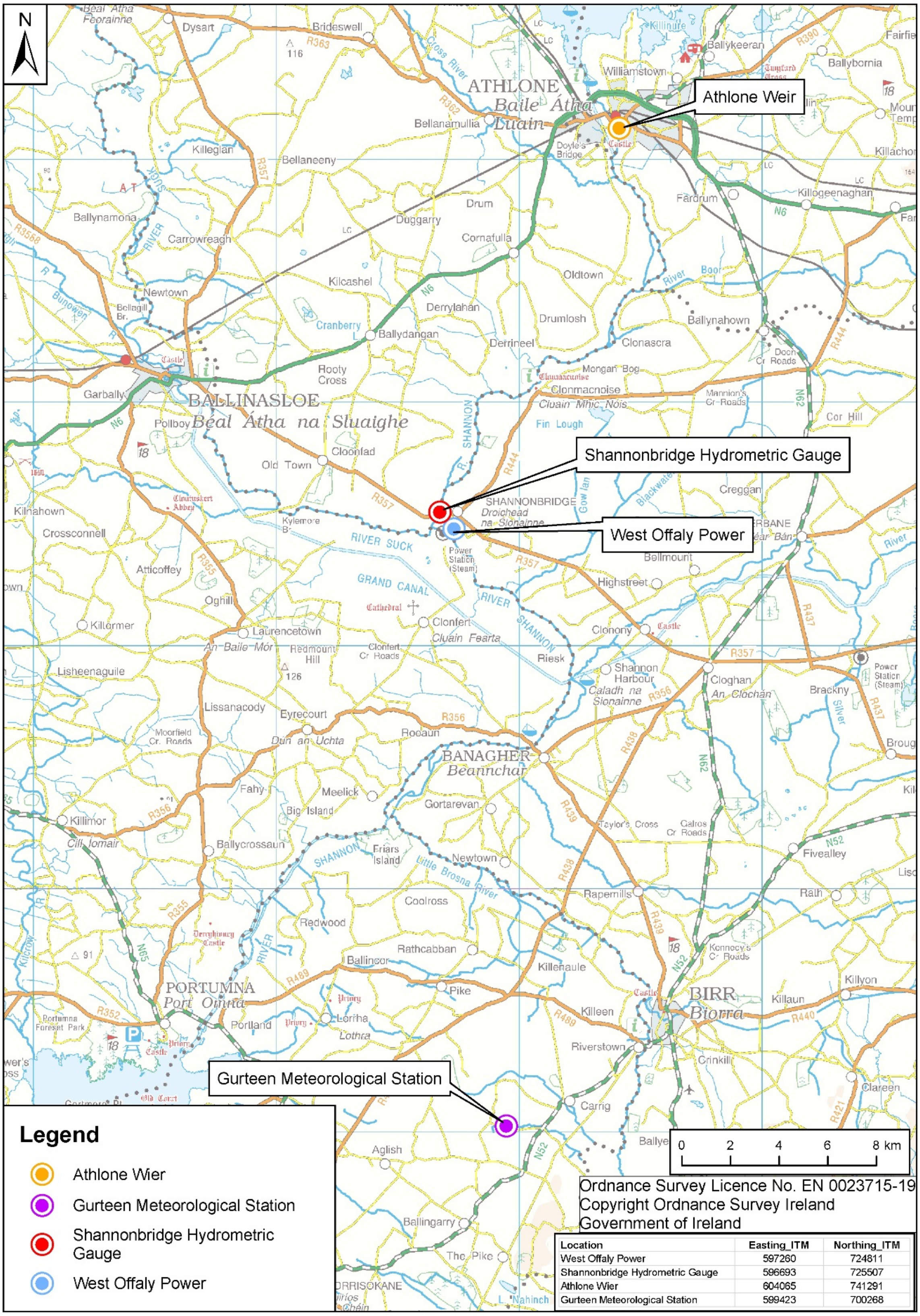


Figure 2-4: Locations of West Offaly Power, Shannonbridge Gauge and Athlone Weir

It should be noted that the operation of the gates at Athlone Weir influences the flow and level regimes in the River Shannon. The water level in Lough Ree is controlled by the weir at

Athlone during low flow conditions. The weir has 15 gates which can be used to vary the level in Lough Ree. Generally, if there is no flooding in the Shannon Callows downstream of Athlone, the water levels in Lough Ree will be drawn down towards the minimum agreed level from October to March to provide for maximum storage for potential winter floods.

In the absence of a rated hydrometric gauge at Shannonbridge, flows on the Shannon are not available at this point. It is necessary to derive river flows using records from elsewhere on the Shannon.

River flow at Shannonbridge can be roughly estimated using data from the hydrometric gauge at Athlone. Recorded water level at Athlone can be used to estimate flows over the weir at Athlone. Flows at Athlone can be related to Shannonbridge using the relative sizes of catchment areas upstream of both sites (described above) as a basis of comparison. There is good correlation between the flow at Athlone and the flow at Shannonbridge.

ESB maintains a database of level and flow records from selected gauges on the Shannon (including Athlone) to assist with the operation of Ardnacrusha Hydroelectric Station.

From the ESB database, daily flows at Athlone from 1951 to 2017 were calculated and a flow duration curve produced. The flow duration curve (FDC) (presented in Figure 2-5) shows the proportion of time that specific flow values at Athlone are equalled or exceeded. The long-term average flow in the Shannon at Athlone is approximately 93m³/s.

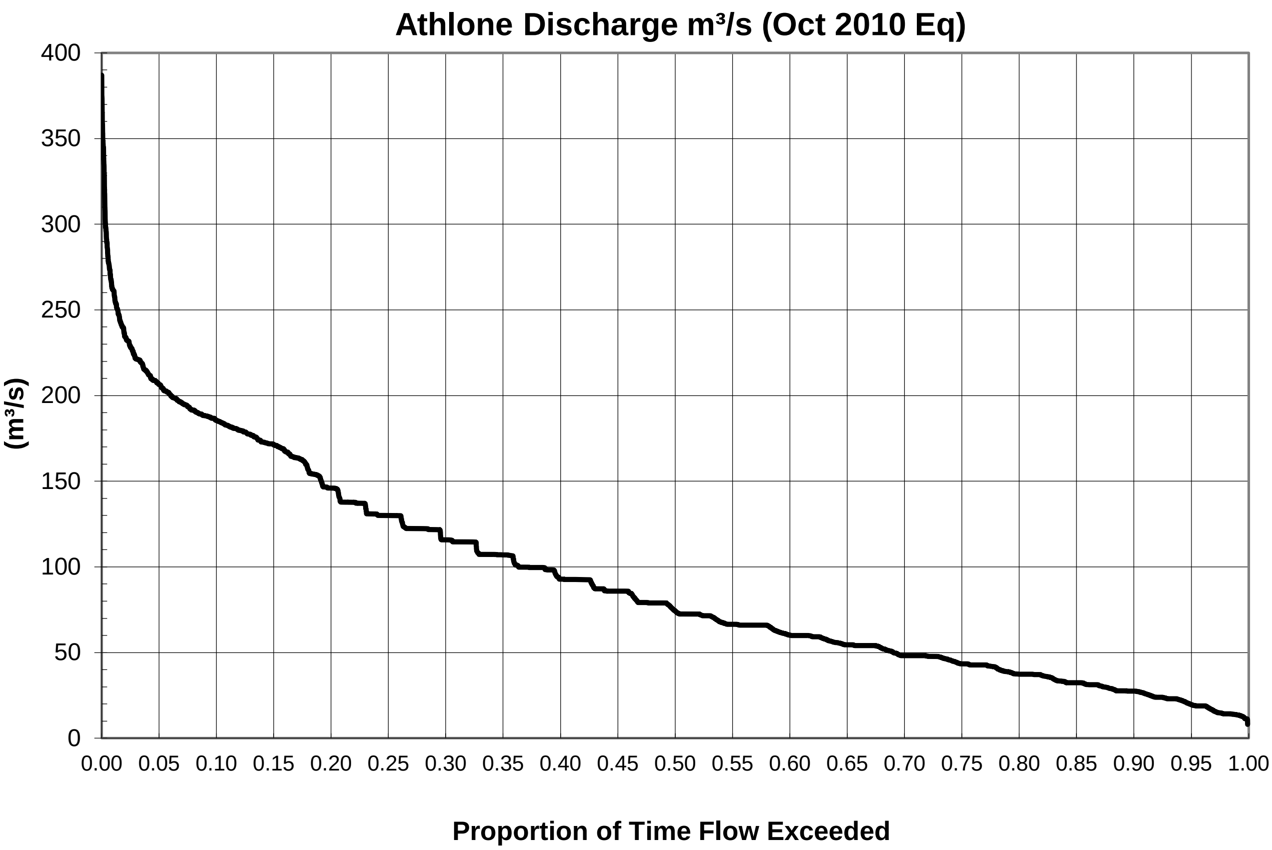


Figure 2-5: Flow Duration Curve - River Shannon at Athlone 1951-2017

2.3 Water Framework Directive

West Offaly Power Generating Station (WOP) is located on the Shannon river at Shannonbridge in the Shannon Catchment 25B. Specifically thermal cooling water is discharged to the lower Shannon River in the WFD sub catchment Shannon [Lower]_010 (Code: IE-SH_25S-012000). No water body status has been assigned by the EPA to this stretch of river (Status: Unassigned on the EPA Envision Mapping system).

Figure 2-6 WFD river water body status at WOP

2.4 Draft River Basin Management Plan for Ireland 2018 - 2021

Consultation on the draft River Basin Management Plan (RBMP) for Ireland 2018 – 2021 concluded at the end of August 2017. The plan sets out the current status of Irish waters, the key challenges and objectives and the key measures to attain the water status requirements set out in the WFD Directive. The Environmental Objectives for the RBMP remain as follows:

- To prevent deterioration of the status of surface waters
- To protect, enhance and restore surface waters with the aim of achieving good status (ecological and chemical) for all water bodies
- For heavily modified water bodies and artificial water bodies, the aim is to protect and enhance those bodies to achieve good ecological potential and good chemical status
- To progressively reduce pollution from priority substances and cease or phase out emissions, discharges and losses of priority hazardous substances into surface waters

A key prioritisation for the second RBMP Cycle is to:

"Work to improve our knowledge and understanding of hydromorphology and barriers as pressures impacting on water quality, including identifying the scale of these issues, and building the expertise necessary to address them."

A key measure is the proposal to

"develop and progress a technical solution to enhance fish connectivity in the Lower Shannon focussing around the Ardnacrusha site. Whilst the ultimate outcome here is the development of such a solution – putting in place the necessary structures for delivery of such a project, assigning responsibilities amongst relevant agencies, and developing an appropriate proposal will be key outcomes necessary before implementation of a final agreed project."

The potential for the thermal discharges from WOP to impact on fish connectivity is therefore a key assessment in terms of understanding whether they act as barriers to achieving fish status required by the WFD and whether any technical solution developed to enhance connectivity at Ardnacrusha would be lessened in effectiveness should this prove both technically feasible and environmentally beneficial.

3 Thermal Plumes Studies

Four boat based surveys of the thermal discharges from West Offaly Power have been undertaken in the River Shannon at Shannonbridge since July 2014. The objective of the surveys was to locate the extent and measure the temperatures of the thermal plume created by the discharge of heated cooling water from the generating station.

The surveys were carried out by Irish Hydrodata (IHD) from a survey launch, to which were attached thermistors at fixed depths below the water surface. The survey method involved steaming the survey boat across the river at varying distances downstream from the discharge location while continuously logging water temperature, position and time data. The surveys were undertaken on

- 31st July 2014
- 5th February 2015
- 18th November 2015
- 28th and 29th April 2016

Table 3-1 presents a summary of hydrological conditions in the Shannon and West Offaly Power station output during each of these surveys. As noted in Section 2.2 above, river flows at Shannonbridge were roughly estimated using data from the hydrometric gauge at Athlone using the relative sizes of catchment areas upstream of both sites as a basis of comparison.

The EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26028) at Shannonbridge as a reference indicator of flow conditions in the Shannon at WOP.

Wind speed and direction can have a significant influence on the behaviour of a thermal plume. Historic wind records from the Met Éireann station at Gurteen, Co. Tipperary, were used to describe conditions at Shannonbridge.

Date	Shannonbridge Level m	Flow at Athlone m³/s	Percentile (%)	Estimated Flow at Shannonbridge m³/s	Station Output MW
31st July 2014	2.140	17	97	23	150
5th February 2015	4.200	191	8	257	150
18th November 2015	4.278	147	19	198	150
28th /29th April 2016	2.760	66	56	89	150

Table 3-1 Flow and Load Conditions during thermal plume surveys at WOP

The surveys of February and November 2015 were undertaken during high flow conditions. They showed that the thermal plume was negligible and the station was compliant with Condition 5.5 of its IEL.

The surveys of July 2014 and April 2016 were undertaken when river flows were below annual average conditions.

As noted, the flow in the River Shannon was low (97 percentile at Athlone) during the 31st July 2014 survey. This survey showed that the thermal plume covered the River Shannon channel downstream of the outlet channel to a depth of 1.3 m. From the survey, it is difficult to determine if the plume extended down to the river bed. Condition 5.5 of the IEL was breached.

It is noted that the results of this survey showed inconsistencies. The survey indicated that the plume crossed the river channel and flowed down the western bank. At a distance approximately 400m downstream of the outfall, the thermal plume disappeared on the western bank and reappeared on the eastern bank. It also showed higher temperatures at a depth of 1.3 m below the water surface than at 0.5 m below the water surface at distances greater than 1 km from the outfall.

The water level at the Shannonbridge hydrometric gauge on the 31st of July 2014 was 2.14 m. From an analysis of the long-term record at this gauge, levels below 2.14 m occur less than 3% of the time period of record. The wind direction was mainly from the South West and the wind speed was approximately 22 km/hr, Force 4 on the Beaufort Scale.

Flow conditions in the Shannon were average during the 28th to 29th of April 2016 survey. This survey showed that the thermal plume was mainly along the eastern bank of the River Shannon. It reached a distance of 525 m downstream of the road bridge. Condition 5.5 of the IEL was not breached. The maximum cross sectional area of the thermal plume was 17% and occurred 250m downstream of the road bridge.

The level at the Shannonbridge gauge on the 29th of April 2016 was 2.77 m. From the analysis of the historic gauge record, levels below 2.77m occurs less than 55% of the time. The wind direction was mainly from the North West and the wind speed was approximately 22 km/hr, Force 4 on the Beaufort Scale.

Non-conformances arising from the results to the survey of July 2014 are set out in Table 3-2.

Non Compliance NC004852 for Electricity Supply Board (West Offaly Power) (P0611-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	17/04/2015
Date of Non-Compliance (1st Date if relates to a period):	31/07/2014
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The results of the July 2014 thermal plume survey on the River Shannon at West Offaly Power during conditions of low flow identified several downstream river cross-sections where the mixing zone exceeded 25% of the surveyed cross-section of the river. The thermal plume is in excess of 1.5 degrees Centigrade outside of the mixing zone (i.e. In relation to temperature, the mixing zone shall not exceed 25% of the cross sectional area of the river at any point). This is a non-compliance with Condition 5.5 of IE Licence P0611-02.	

Non Compliance NC004853 for Electricity Supply Board (West Offaly Power) (P0611-02)	
Non Compliance Type:	Miscellaneous
Non Compliance Condition:	5.1
Notification Date:	17/04/2015
Date of Non-Compliance (1st Date if relates to a period):	31/07/2014
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
'The results of the July 2014 thermal plume survey on the River Shannon at Shannonbridge during conditions of low flow identified that temperatures of more than 1.5 degrees Centigrade above the ambient temperature were maintained for 2kms downstream of the combined PS-SW1 and PS-SW2 discharge point from West Offaly Power. The Agency considers this to be an emission of environmental significance. This is a non-compliance with Condition 5.1 of IE Licence P0611-02.	

Table 3-2 WOP Non-Conformances associated with results of survey of July 2014.

The following Compliance Investigation (CI) is related to the survey of July 2014:

- CI 884, Opened 21/10/2014. Risk –Low. Status –Active.

4 Continuous Temperature Monitoring

4.1 Introduction

Following the thermal plume studies described in Section 3 above, a programme of continuous temperature monitoring was instigated in July 2016 at seven fixed locations in the river Shannon in the vicinity of West Offaly Power at Shannonbridge. At each location, three temperature thermistors with loggers were deployed to measure and record temperatures at 0.3m, 0.8m and 1.5m below the water surface. Figure 4-1 below, maps the locations of the continuous monitoring points which are designated as points S1 to S7. The locations are tabulated in Table 4-1.

Figure 4-1: Continuous Monitoring Points at WOP

One location is at the cooling water inlet (designated as S1) and the remaining six are downstream of the cooling water discharge (designated as locations S2 to S7).

ID	Location	Easting (m ITM)	Northing (m ITM)	Logger Depth T1 (m)	Logger Depth T2 (m)	Logger Depth T3 (m)
S1	U/s 1 (intake)	597273	724473	0.3	0.8	1.5
S2	D/s 1 West	597369	724068	0.3	0.8	1.5
S3	D/s 2 West	597467	723964	0.3	0.8	1.5
S4	D/s 2 East	597581	723903	0.3	0.8	1.5
S5	D/s 3 West	597660	723710	0.3	0.8	1.5
S6	D/s 3 East	597764	723726	0.3	0.8	1.5
S7	D/s 4 East	598123	723466	0.3	0.8	1.5

Table 4-1: Continuous Monitoring Points at WOP

The continuous monitoring programme has been ongoing since the 11th of July 2016. Temperature records at 5 minute intervals are available from that date up to the 31st of December 2017. In addition, the assessment considered station load (MW), flow conditions in the River Shannon, water levels at Shannonbridge and meteorological conditions. The results of the continuous monitoring are discussed below in Sections 4.2, 4.3 and 4.4.

4.2 Thermal Plume

From a review of the continuous temperature data for locations S1 to S7, WOP station load, meteorological records and the water levels at Shannonbridge hydrometric gauge (See Figure 4-2 below) the following conclusions are drawn for the period 11th of July 2016 to the end of December 2017:

- Below average rainfall in the period from the 11/07/2016 to the 31/08/2017 resulted in generally low water levels and low flows in the river Shannon at Shannonbridge. The water level at Shannonbridge has been below the 50 percentile level of 2.85 m for 80% of the time for this period. There has been above average rainfall from 01/09/2017 to the 31/12/2017 resulting high water levels and high flows.
- Low water levels and low flows occurred from the beginning of May 2017 to the middle of August 2017. Flows were particularly low in the periods 10/05/2017 to 16/05/2017, 31/05/2017 to 10/06/2017 and 04/07/2017 to 26/07/2017. The calculated flows for Athlone for these periods were less than 20 m^3/s which is the 95 percentile flow (ESB Database).
- There is no observable temperature rise at Locations S2, S3 and S5 on the western bank of the river Shannon until water levels fall below 2.3m at the Shannonbridge gauge.
- At water levels above 2.3m, the thermal plume tends to flow along the eastern bank of the river Shannon. The maximum temperature rise is recorded at monitoring point S4 on the east bank of the river.
- At levels below 2.3 m, the thermal plume tends to flow across the river along the west bank. The thermal plume was evident from the 15/08/2016 to the 22/08/2016 at S3 and S5 but not in S2 on the west bank. It was not evident at S4, S6 and S7 on the east bank. Maximum temperature rise was recorded at S3. The water levels at this time were less than 2.3 m but greater than 2.25 m
- At levels below 2.25 m, the thermal plume tends to occupy the entire river channel to a depth of at least 1.5m. Levels below 2.25 m occurred for a significant portion of the time from May 2017 to August 2017 and the thermal plume is observable at all monitoring locations at these low levels. Maximum temperature rise occurs at monitoring points S2 and S3. This behaviour was also observed in the thermal plume survey of July 2014 when levels were also low.
- From the continuous temperature monitoring at the 6 locations downstream, it is not possible to determine if the thermal plume covers more than 25% of the cross sectional area at any location when levels are above approximately 2.25 m.
- Levels above the 50 percentile level occurred on a number of dates. Short periods of higher water level occurred from the 24/12/2016 to the 21/01/2017, between 26/02/2017 and 11/04/2017and between the 30/08/2017 and the 31/12/2017. The maximum level reached between 24/12/2016 and 21/01/2017 was 3.152 m, and occurred on the 08/01/2017. The maximum level reached between 26/02/2017 and 11/04/2017 was 4.346 m, above the 10 percentile level of 4.196 m and occurred on

the 09/03/2017. The maximum level reached between 30/08/2017 and 31/12/2017 was 4.334 m, above the 10 percentile level and occurred on the 31/12/2017.

The percentile levels have been obtained from the OPW web site www.waterlevel.ie

Figure 4-2 presents a summary of recorded water levels at the Shannonbridge gauge since the start of the monitoring programme taken from www.waterlevel.ie.

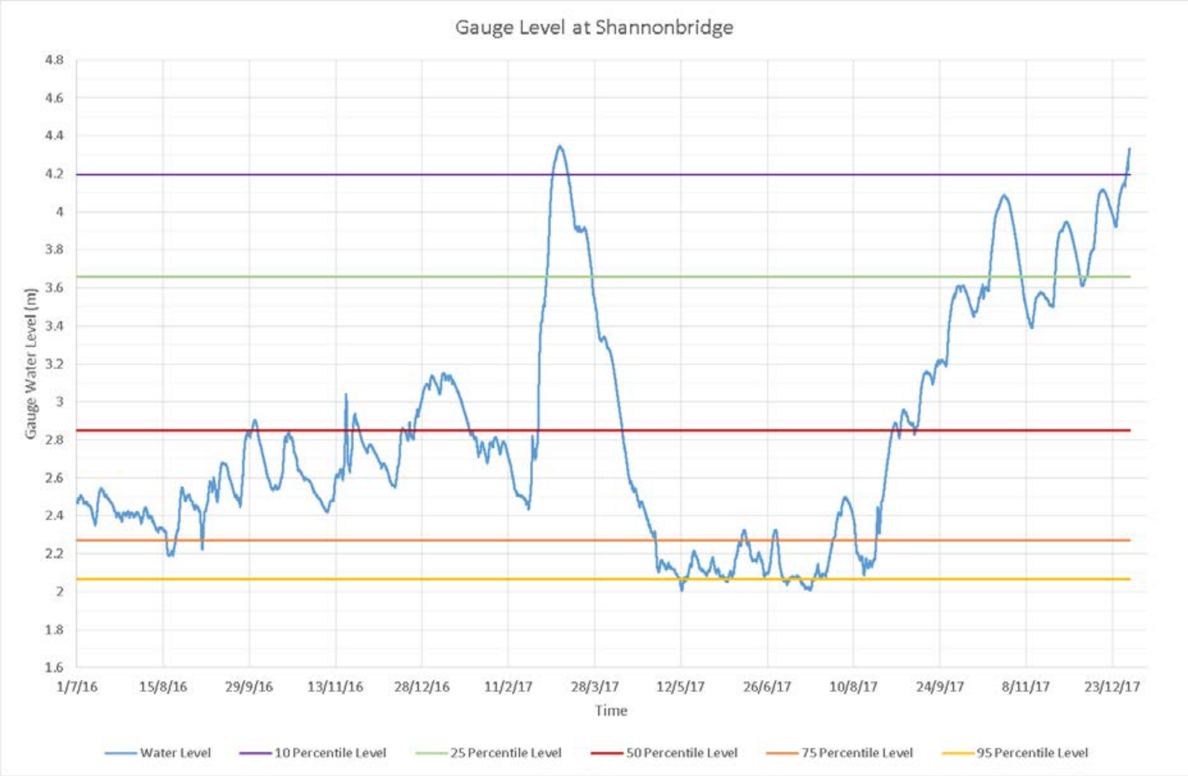


Figure 4-2 Water Levels at Shannonbridge (www.waterlevel.ie.)

4.3 General Ambient Temperature Trends

Monitoring point S1 measures the ambient temperature at Shannonbridge. The water temperature is measured at depths of 0.3m, 0.5m and 1.5m from the water surface. The temperature measurements show:

- The temperature is not uniform throughout the water column. Temperatures at the surface are higher than lower down in the water column. Temperature measurements taken during the thermal plume survey of April 2016 also show this uniformity.
- The diurnal variation is temperature is generally less than 1 ^{o}C. However it can be greater in the summer during fine weather.
- There is a distinct seasonal variation in temperature with maximum temperatures occurring in June and July and minimum temperatures in December and January. It appears that the main factors that affect the water temperature are air temperature, sunshine and the length of the day.

Figure 4-3 shows the trends in background temperature (i.e. the temperature at 0.3 m depth upstream of the thermal discharge) for each of 13 reporting periods at WOP. The highest ambient temperatures (20-22°C) occurred in the period late-May-June (mainly June) 2017, and they just reached 20 °C in July-August (2016) and June-August (2017). Temperatures were generally below 10°C in the period November to March in both years, between 10°C and 15°C mainly in September and October in both years and between 15°C and 20°C between late April and August.

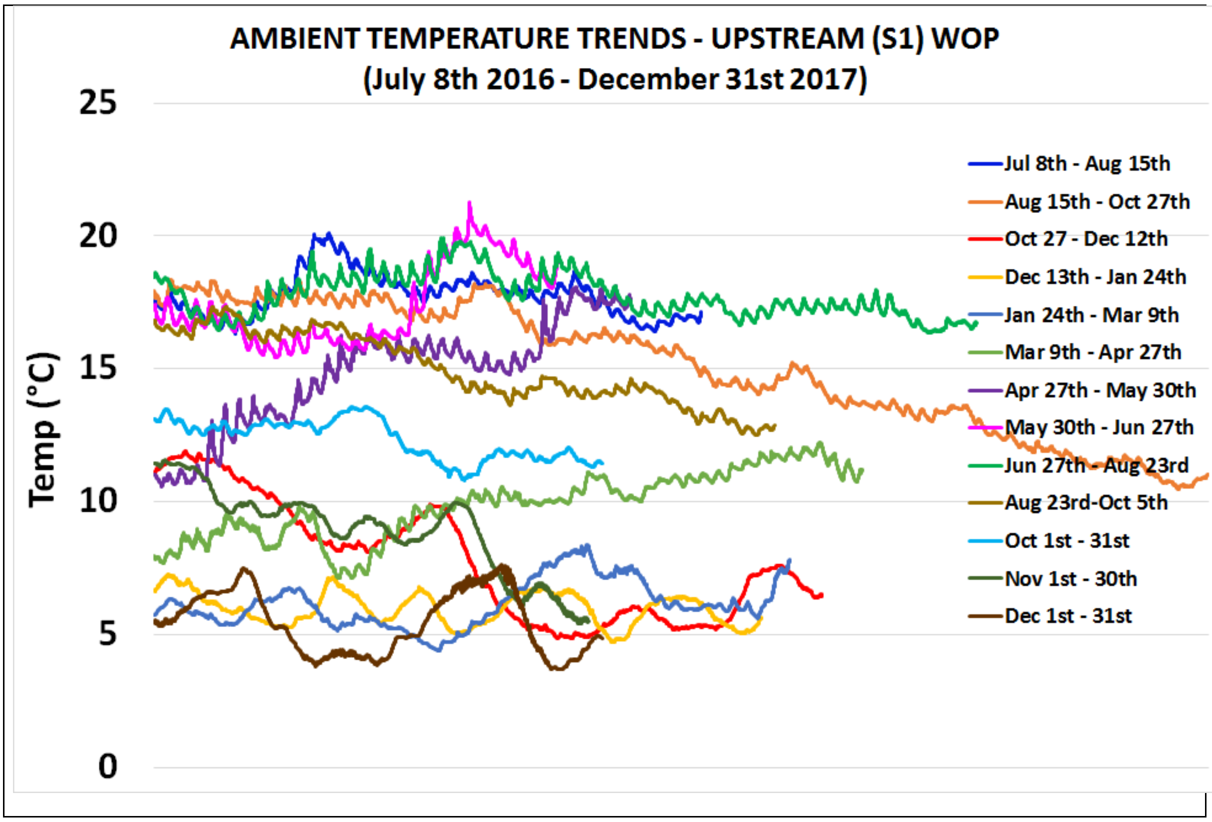


Figure 4-3 Upstream (S1 - ambient) temperatures at 0.3m depth at WOP for 13 reporting periods between July 2016 and December 2017

4.4 Temperature Averages

The cooling water discharge from West Offaly Power has a positive buoyancy. The maximum temperature rise will occur at the surface and decrease with depth.

Figure A-1 in Appendix A presents, for each of the 13 reporting periods, the average and maximum absolute temperatures at each of the WOP stations at each depth (left side graphs) and the incremental increase in average temperature at each of the stations downstream of the cooling water discharges and also at each depth (right side graphs). The latter were calculated by subtracting the average upstream (ambient) temperature at each depth (0.3m, 0.5m and 1.5m) from the corresponding average temperature at the downstream stations for each of the monitoring periods in turn.

In terms of average incremental increase in temperature, the highest reached was 3°C at 0.3m depth at Site S2 and a little less at Site S3, during the May/June 2017 recording period, with all other average incremental increases below 2°C and often at or below 1°C.

During the first six monitoring periods, Sites S2, S3 and S5 on the western side of the channel registered virtually no increase in temperature relative to the upstream temperature, with all of the increase being recorded along the eastern (left) bank at Sites S4, S6 and S7, with a tendency for the lowest incremental increases to be at Site S7, the farthest downstream monitoring location. However, there was a clear change in this pattern in the next 3 recording periods assessed (April/May 2017, May/June 2017 and June/August 2017). During these periods the plume spread over to the western side of the channel with Sites S2 and S3 having the highest incremental increase in temperature ranging from an average of 1.5-3°C above ambient. At the same time, the bottom temperature (1.5m) at the same sites was about 1°C cooler, ranging from 0.75-1.8°C above ambient. Although not always the case, S3 tended to be about 0.5°C lower than S2, at least at the surface (0.3m) and mid (0.5m) depths. However, the average temperature rise at Sites S5, S6 and S7 was generally below 1.5-1.7°C for all 13 reporting periods and more often around 1°C or less. S4 tended to lie between these figures and those for S3 but in any case was always at or less than 2°C on average above ambient.

Another feature of most of the WOP data, was the comparatively small difference in average temperature between the 0.3m and deeper sites which is also noticeable in the incremental temperature increases at sites. However, it was noteworthy that during the warmer periods i.e. April-May 2017, May-June 2017 and June-August 2017 there was a noticeably cooler temperature at the deepest station (1.5m) at Sites 2 and 3 in particular and at S4 in June-August 2017. Indeed this deeper station only noticeably exceeded 1°C above ambient in May-June 2017 when ranged from about 1.5-1.9°C above at Sites 2-4 The only slight contrast to this was evident at Sites S2 and S3 in May/June 2017 and to a lesser extent April/May 2017 when there were noticeable, albeit small-scale, differences between the 0.3m, 0.5 and 1.5m depths, with a tendency for the deeper stations to be cooler.

In terms of maximum absolute temperatures, the highest these reached downstream of WOP was during May/June 2017 and June-August 2017 when they peaked at 25.3°C and 26.39°C respectively (both at Site S2 surface (0.3m). On the same 2 occasions at the same site, the maximum temperature at the deeper station (1.5m) was 23.9°C and 22.4°C respectively.

Non-conformances arising from the results to the programme of continuous monitoring at WOP are set out below.

Non Compliance NC009133 for Electricity Supply Board (West Offaly Power) (P0611-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	16/08/2017
Date of Non-Compliance (1st Date if relates to a period):	16/08/2017
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The continuous monitoring temperature data for Period 7: April 2017 - May 2017 on the River Shannon at West Offaly Power demonstrated that the combined cooling water and screen wash water discharge (Emission point reference number: Combined PS-SW1 and PS-SW2) artificially increased the ambient temperature of the receiving water by more than 1.5 degrees centigrade. The data also demonstrated that the mixing zone for temperature exceeded 25% of the cross-sectional area of the river. Temperature increases were noted on both east and west banks and more than a kilometre downstream. This is a non-compliance with Condition 5.5 of IE Licence P0611-02. Identified several downstream river cross-sections where the mixing zone exceeded 25% of the surveyed cross-section of the river. The thermal plume is in excess of 1.5 degrees Centigrade outside the mixing zone (i.e. in relation to temperature, the mixing zone shall not exceed 25% of the cross-sectional area of the river at any point).	
Non Compliance NC009619 for Electricity Supply Board (West Offaly Power) (P0611-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	30/05/2017
Date of Non-Compliance (1st Date if relates to a period):	01/09/2017
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The continuous monitoring temperature data for Period 8: May 2017 - June 2017 on the River Shannon at West Offaly Power demonstrated that the combined cooling water and screen wash water discharge (Emission point reference number: Combined PS-SW1 and PS-SW2) artificially increased the ambient temperature of the receiving water by more than 1.5 degrees centigrade. The data also demonstrated that the mixing zone for temperature exceeded 25% of the cross-sectional area of the river. Temperature increases were noted on both east and west banks and more than a kilometre downstream. This is a non-compliance with Condition 5.5 of IE Licence P0611-02.	
Non Compliance NC009621 for Electricity Supply Board (West Offaly Power) (P0611-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	01/09/2017
Date of Non-Compliance (1st Date if relates to a period):	28/06/2017
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The continuous monitoring temperature data for Period 9: June 2017 - August 2017 on the River Shannon at West Offaly Power demonstrated that the combined cooling water and screen wash water discharge (Emission point reference number: Combined PS-SW1 and PS-SW2) artificially increased the ambient temperature of the receiving water by more than 1.5 degrees centigrade. The data also demonstrated that the mixing zone for temperature exceeded 25% of the cross-sectional area of the river. Temperature increases were noted on both east and west banks and more than a kilometre downstream. This is a non-compliance with Condition 5.5 of IE Licence P0611-02.	

Table 4-2 Non-Conformances associated with results of Continuous Monitoring at WOP

5 Fisheries

In July 2016, ASU undertook a review of the thermal sensitivity and related biology of all those fish species recorded by Inland Fisheries Ireland (IFI) in 2010 from or near the WOP sections of the River Shannon and the theoretical risk that the discharges might pose for them. In addition, in September 2016 ASU produced a second shorter report in response to specific questions posed by IFI personnel in response to the review. Both of these documents will be referenced as required in the following fisheries-related aspect of the synthesis report. However, the greater emphasis in this section will be on the findings of the five separate fyke-net surveys undertaken by Denis Doherty, ESB Fisheries Scientist, during August 2016, October 2016, February 2017, November 2017 and December 2017 at WOP as these are to date the most focused fisheries surveys at these sites (Doherty, 2017). Reference will also be made to the results of a Water Framework Directive (WFD) fish monitoring survey undertaken by IFI on the Shannon in 2010 on the Shannon at Clonmacnoise just upstream of the WOP stretch and the 2016 IFI survey (IFI, 2017), which included sites just upstream and downstream of WOP also.

5.1 Fyke Net Surveys

The 5 fyke net survey campaigns were undertaken by Denis Doherty (ESB Fisheries) and his team in August 2016, October 2016, February 2017, November 2017 and December 2017. The surveys consisted of 10 sets of three fyke nets set at 5 paired sites i.e. 5 along the right (west) bank and left (east) bank of the river at both sites, the first pair situated upstream of the power station thermal discharge in each case (Doherty, 2017). The locations of each set of nets at are presented in Figure 5-1. The distribution of nets cover the same stretch used for biological sampling (2014-2016). Table 5-1 lists the dates of the surveys and the maximum temperatures recorded at the same or nearby sites during the week of the surveys at WOP. Figure 5-2 presents the depth averaged average temperatures at each of the fishing sites for each of the three seasonal surveys. These data have been extracted from the IHD continuous temperature monitoring data for WOP for the weeks commencing the survey dates or dates bracketing the survey dates as indicated in Table 5-1. As the two sets of data do not overlap precisely in terms of locations, the nearest logical site or combination of sites for the temperature monitoring was used to represent temperature data at the nearest left and right bank fishing sites..

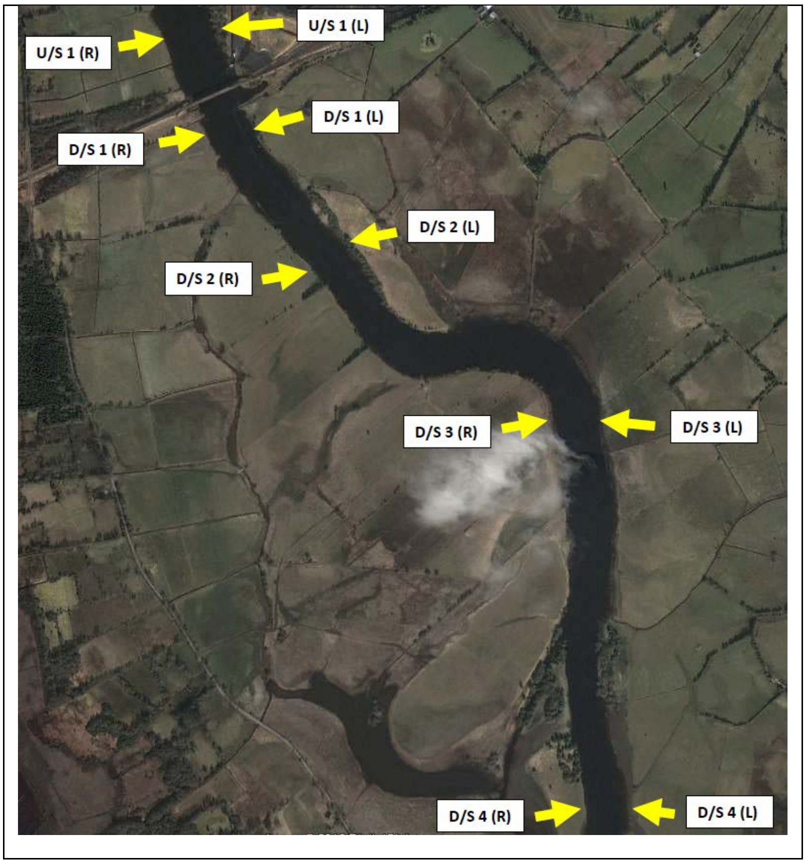


Figure 5-1 Aerial photos showing fyke net fishing locations in the Shannon River at WOP

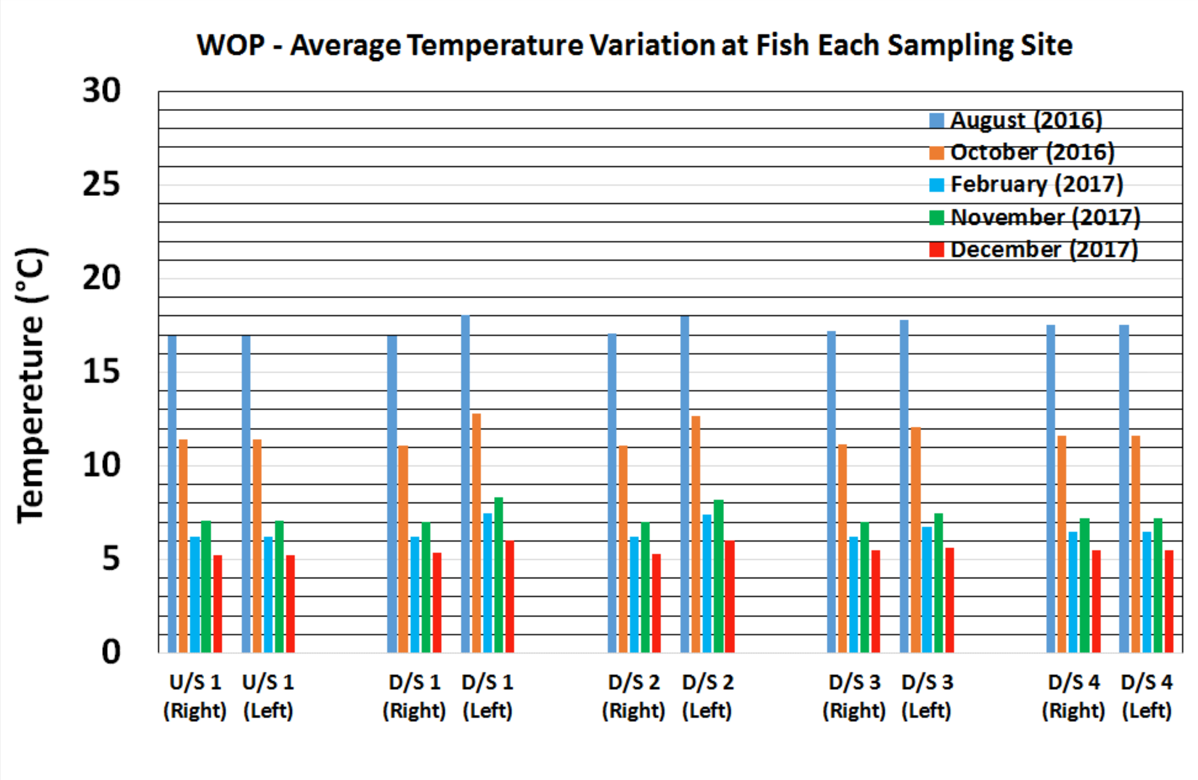


Figure 5-2 Average depth-averaged temperature at or nearby the 5 paired fyke net sampling stations at WOP for each of the 5 fishing surveys. (Data extracted from IHD temperature monitoring reports).

5.1.1 Species Present and Overall & Relative Abundances

Table 5-2 lists the 9 fish species caught at WOP in decreasing order of total abundance as well as a breakdown of absolute numbers and combined percentages for each of the 5 survey periods. Table 5-3 presents the individual fish numbers taken in each net during each survey. Figure A-2 in Appendix A shows the relative abundance for each species in all surveys, while Figure A-3 in Appendix A shows the same data broken down by survey (August 2016, October 2016 and February 2017).

The list in Table 5-2 is dominated in terms of species and numbers by coarse fish and eel whereas brown trout (the only salmonid present) was represented by comparatively small numbers overall. A single lamprey was also caught (in February 2017) which is more likely a reflection of the fishing method than a true representation of the species abundance, which is known from the 2010 IFI electrofishing surveys to occur frequently in the area.

An obvious feature of the data was the higher number of fish taken in the August 2016 survey compared to all 4 subsequent surveys. During these later months, only between a third (33%) and a half (50%) of the August numbers were taken at the site. This may be because the much lower temperatures during the later surveys reduced the likelihood of capture due to lower fish activity rates. It may also reflect the movement away from the sites of some species, perhaps to lake waters or to deeper areas of the river. The three species that bucked this trend were eel, roach and hybrids. In February 2017, eels were nearly 4 times more abundant in February than in August, roach were more or less as abundant in November and December

2017, while hybrids were fairly similar in abundance in each of the 5 surveys, with the highest numbers recorded in February 2017 (Table 5-2 and Figure A-3). The higher representation of eels in February 2017 is considered by Denis Doherty to be due to the later out-migration of silver eel on the Shannon in 2016, which was corroborated by the records of eel numbers at Killaloe Weir for the 2016/2017 period (Doherty, 2017).

Survey Dates W/C	U/S Temp (°C)	Range of D/S Surface Max Temp (°C)
	Shannon River at WOP	Shannon River at WOP
Aug 8th 2016	17.7	18.0 - 19.1
Oct 17th 2016	11.9	11.5 - 13.7
Feb 27th 2017	7.43	7.6 - 9.3
Nov (21st-28th)	6.9 - 9.4	5.9 - 10.8
Dec (16th-21st)	4.5 - 6.9	3.6 - 7.9

Table 5-1 Fyke net survey dates and maximum temperatures at WOP

WOP	Roach	Perch	Eel	*Hybrids	Trout	Pike	Gudgeon	Bream	Lamprey	Tots
Aug-16	35	57	9	3	-	9	2	3	-	**118**
Oct-16	19	6	4	6	1	-	2	-	-	**38**
Feb-17	9	2	33	16	3	-	-	1	1	**65**
Nov-17	37	2	7	3	1	1	-	-	-	**51**
Dec-17	30	1	3	5	8	-	1	-	-	**48**
Tots	**130**	**68**	**56**	**33**	**13**	**10**	**5**	**4**	**1**	**320**
%	**40.6**	**21.3**	**17.5**	**10.3**	**4.1**	**3.1**	**1.6**	**1.3**	**0.3**	

* roach x bream

Table 5-2 Total of each species caught during each survey in the Shannon River at WOP in decreasing order

August 2016 (8th)									
Site	**Perch**	**Roach**	**Bream**	***Hybrids**	**Eel**	**Pike**	**Gudgeon**	**Trout**	**Lamprey**
U/S 1 - R	4				3	1			
U/S 1 - L	3	5				2			
D/S 1 - R	6	6				1			
D/S 1 - L	18	5	1	3	1	1			
D/S 2 - R	1	2			1				
D/S 2 - L	5	5			1				
D/S 3 - R	4	1	1		2	2			
D/S 3 - L	7	6	1			2			
D/S 4 - R	4	2							
D/S 4 - L	5	3			1		2		
October 2016 (12th)									
Site	**Perch**	**Roach**	**Bream**	***Hybrids**	**Eel**	**Pike**	**Gudgeon**	**Trout**	**Lamprey**
U/S 1 - R	4	4			1				
U/S 1 - L									
D/S 1 - R		4					1		
D/S 1 - L		1		1			1		
D/S 2 - R		1			2				
D/S 2 - L		3		1					
D/S 3 - R		1		1	1				
D/S 3 - L		2		1					
D/S 4 - R	2	1						1	
D/S 4 - L		2		2					
February 2017 (27th)									
Site	**Perch**	**Roach**	**Bream**	***Hybrids**	**Eel**	**Pike**	**Gudgeon**	**Trout**	**Lamprey**
U/S 1 - R				3	3				
U/S 1 - L		1		3	13				
D/S 1 - R									
D/S 1 - L	2	1		1	3				
D/S 2 - R					3				
D/S 2 - L		1		3	3				1
D/S 3 - R		3	1	4	3			1	
D/S 3 - L		3		2	4				
D/S 4 - R								2	
D/S 4 - L					1				

*Hybrids = Roach x Bream

Table 5-3 Fish numbers caught at each site in the Shannon River at WOP in the 5 surveys

November 2017 (26th)									
Site	**Perch**	**Roach**	**Bream**	**Hybrids**	**Eel**	**Pike**	**Gudgeon**	**Trout**	**Lamprey**
U/S 1 - R		4			3	1			
U/S 1 - L		5							
D/S 1 - R		1			2				
D/S 1 - L	1	11		3	2				
D/S 2 - R									
D/S 2 - L		2							
D/S 3 - R		6							
D/S 3 - L									
D/S 4 - R		4							
D/S 4 - L	1	4						1	
December 2017 (19th)									
Site	**Perch**	**Roach**	**Bream**	**Hybrids**	**Eel**	**Pike**	**Gudgeon**	**Trout**	**Lamprey**
U/S 1 - R		2		2				1	
U/S 1 - L		6		2	1				
D/S 1 - R	1	6						3	
D/S 1 - L		4			1			3	
D/S 2 - R									
D/S 2 - L									
D/S 3 - R		9			1				
D/S 3 - L		2							
D/S 4 - R		1		1				1	
D/S 4 - L									

*Hybrids = Roach x Bream

Table 5-3 contd:

5.1.2 Possible Temperature Related Affects in the Data

In order to discern possible temperature-related effects in the data, numbers of each species captured in left bank nets (i.e. on the warmer water side of the channel) and in the right bank nets (i.e. on the cooler water side of the channel) were plotted for each of the 5 survey events at WOP (Figure 5-3). While it is important to bear in mind that these are aggregate totals for netting sites along each bank in each case, including the single left and right bank nets upstream of each station, nevertheless a number of trends are apparent. Firstly, in most cases most species were taken in broadly similar numbers at both sides of the channel. Moreover, the apparent preference for one side or the other in any given species could vary from one survey to the next and finding definite patterns was not easy. Trout were absent from catches during August 2016 when upstream and right bank temperatures were close to optimum for the species i.e. ~17°C, whereas they were present in small numbers in the 4 remaining surveys. During these surveys they appeared to show a preference for the right (cooler) side of the channel. However, the numbers involved were so small and the temperature differential so modest, that one couldn't point to a definite trend. It is noteworthy that in both the 2010 and 2016 IFI surveys of the main channel carried out in May and July respectively, no trout were recorded in the main stem of the river.

Eel appear to show left bank preference at WOP in February 2017. However, when the relatively large contribution of the upstream left bank net is discounted, this observation doesn't hold (Table 5-3). The fisheries literature review (ASU, 2016) clearly demonstrated that eel are a thermally tolerant species and none of the temperatures recorded at any netting sites at WOP is likely to have presented a thermal challenge to the species in any of 5 fyke net surveys.

Among the other species, perch shows a slight left bank bias in August, while in the remaining surveys, numbers are too low to make a call. Roach also show a marginal left bank preference in August and also in November but at other times it wasn't at all clear.

It is worth noting that, in all 5 surveys, there is a left bank –right bank temperature differential at the 4 downstream sites as indicated in the summary temperature data shown in Figure 5-2. However, the difference for Sites 1 d/s 1 to 3 d/s is modest and only very marginal at 4 d/s.

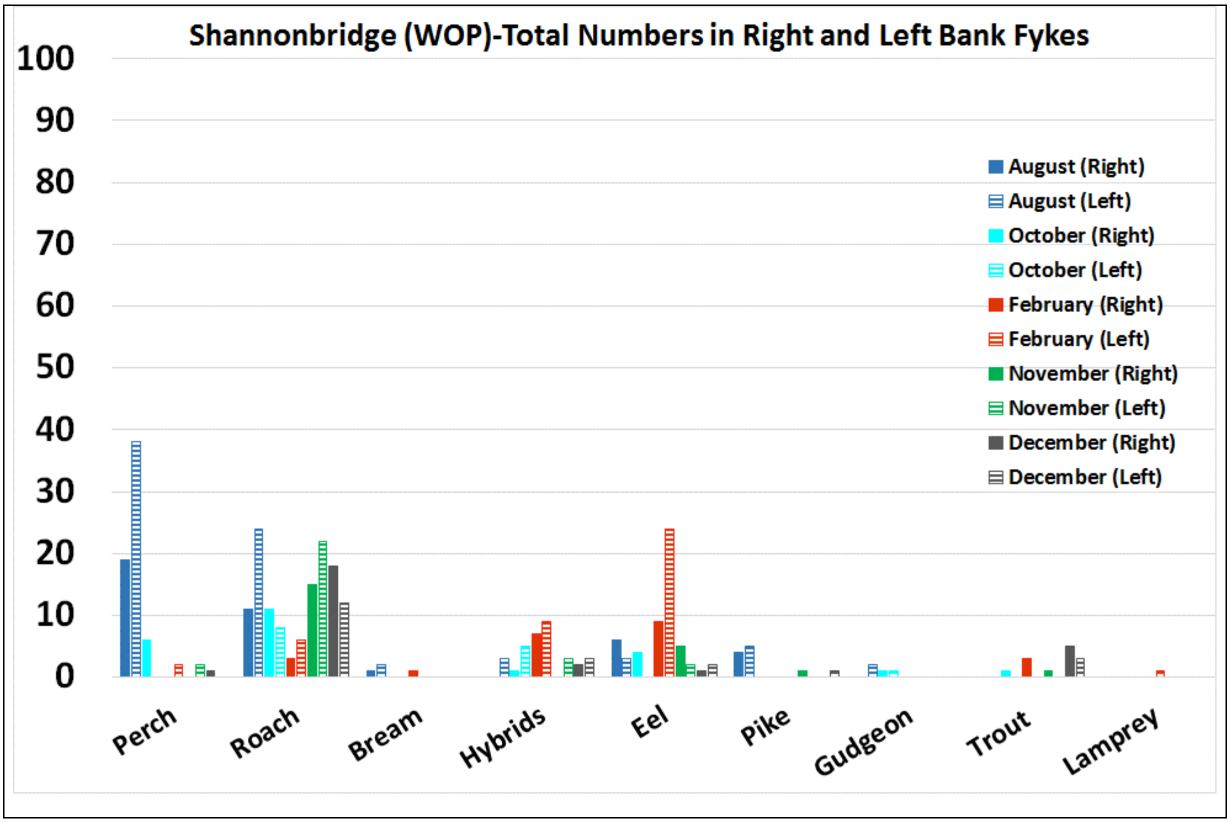


Figure 5-3 This shows the total number of fish of each species collected at all left (warm water) and right (cooler water) sites in each of the 5 survey periods at WOP

5.1.3 Overall Conclusions – Fyke Net Survey

A number of tentative conclusions can be drawn from the 5 fyke net surveys as follows:

- The overwhelming numerical dominance of cyprinid fish, as well as the greater diversity of this group at WOP, indicates that the main channel of the Shannon at this location can be classified as a cyprinid water.
- All species recorded more than once were encountered in both left and right bank nets at sites downstream of the thermal discharge which indicates that the presence of warmer water isn't excluding any of these species. Numbers of lamprey were too small to draw any definite conclusions in that regard. However, available thermal tolerance information on lamprey would suggest that this species would be unlikely to be adversely impacted in general (ASU, 2016).
- While some left-bank preference may be occurring among perch and roach, the evidence isn't conclusive.
- The data also shows a strong seasonal trend with numbers of most species reducing and some disappearing in the surveys during colder months.

5.2 Comparison of IFI data (2010 and 2016) with Fyke Net Surveys (2016/2017)

In summer 2010, IFI undertook electrofishing surveys just upstream the Shannonbridge stretch at Clonmacnoise. In July 2016, they surveyed 23 main-channel sites from Carrick-on-Shannon to Athlone, including sites at just upstream and downstream of WOP. The species and proportional composition of the finding of these surveys are presented in Figure 5-4 and Figure 5-5 as pie charts. When these are compared to the current fyke net surveys results (Doherty, 2017) a number of observations can be made as follows:

- All the species captured in the IFI surveys were also present in the fyke net surveys.
- Eels were proportionally better represented in the fyke net surveys, which would be expected, as fyke nets are specifically designed to capture eels.
- More lamprey were captured in the IFI survey (in 2010) which can be explained by the fact that juveniles (ammocoetes) would be generally be too small to be captured in fyke nets and only caught incidentally.
- No trout were captured in the IFI surveys which were undertaken during May and July, which concurs to some extent with the August 2016 result in the fyke net survey when trout were absent from WOP nets.
- Relatively more roach than perch were taken in the IFI surveys in 2016 whereas, in the fyke surveys in August 2016 perch more abundant but thereafter roach were more common. The reason for this perceived difference isn't immediately apparent.
- It is worth noting that the 2016 IFI survey used a different capture method than the 2010 survey, which may account for some at least of the differences in diversity and relative dominance displayed in the 2010 and 2016 surveys.

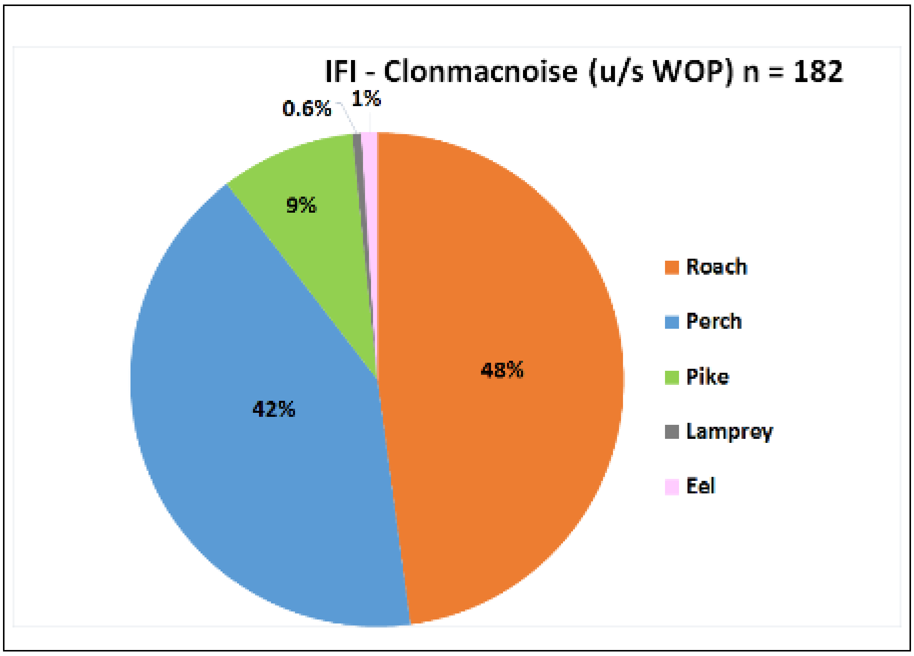


Figure 5-4 Proportional composition of fish species taken in an electrofishing survey in 2010 by IFI upstream of WOP at Clonmacnoise

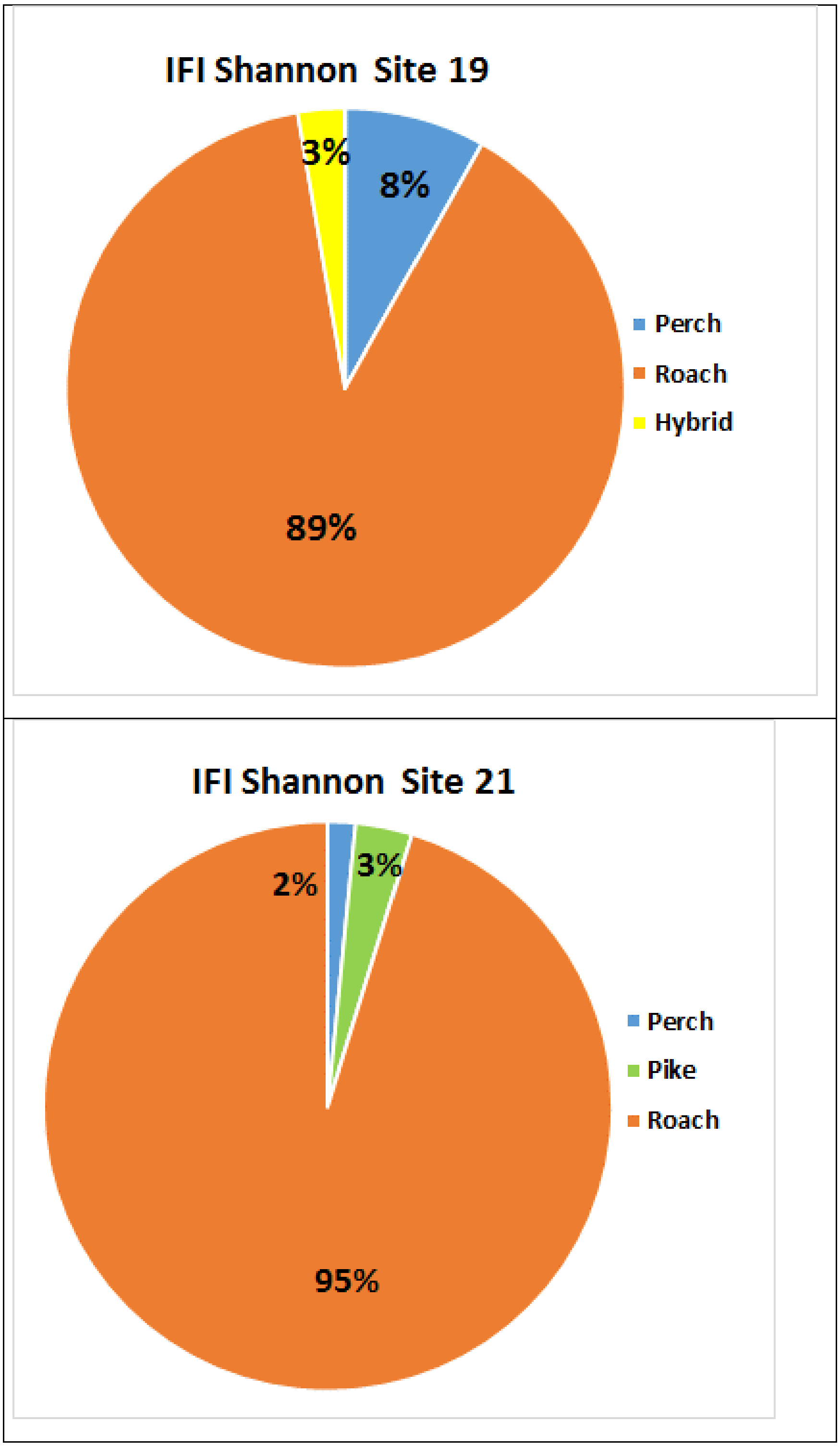


Figure 5-5 Proportional composition of fish species (based on CPUE) taken in an electrofishing survey in 2016 by IFI upstream (Site 19) and downstream (Site 21) of WOP at Shannonbridge

5.3 Literature Review of Potential Fisheries Impacts

A literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the WOP area was undertaken together with a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. The review report was prepared by Gerard Morgan M.Sc. of the Aquatic Services Unit and submitted to the EPA with additional information being supplied in response to specific questions submitted (ASU, 2016). An addendum to the report has been prepared which specifically addresses the potential thermal plume impact on salmon based on existing data, fish surveys and continuous temperature monitoring data collected to date. The Literature Review, Response to specific queries and Addendum are provided in Appendix B.

The main summary and conclusions of the 2016 review are as follows:

- The current review and risk assessment would suggest that the thermal discharge at WOP is likely to have only minor impacts on the resident fish community under average conditions of flow and temperature in any given month. In some warmer years during conditions of low flow, particularly in the period June-August, all fish species may exhibit some avoidance behaviour of the upper 100-300m downstream of the station outfall at WOP, especially the discharge channel. Any trout that are present downstream of the discharges are likely to be the most sensitive of the fish present and therefore the most likely to avoid smaller areas downstream of both outfalls. Out-migrating silver eels are very unlikely to be adversely affected by the discharges because of their mainly late autumn to early spring migration window and the propensity for the greatest rates of migrations to be accompanied by increased discharge in the river. In the warmest years where these coincide with low flows, a small portion of the returning adult salmon population may be delayed in their upstream migration downstream of both plants. The vast majority of out-migrating salmon smolts are likely to descend past both plants without interruption. There is a slight possibility that during warmer and lower than usual flow conditions in May or early June a portion of the smolts may be exposed to an increased risk of predation by fish or birds due to a temperature-induced reduction in swimming speed. Neither the potential impacts on adults nor that on smolts is likely to result in a significant negative impacts on the population given that only a very small portion of the population should be affected in any one year and the occurrence, especially in relation to smolts is likely to be rare.

Subsequent to the report, a more specific assessment of the potential impact on migrating salmon (adults and smolts), based on an analysis of the continuous (5-minute) river temperature monitoring from July 2016 to December 2017, combined with more recent adult salmon census data from ESB Fisheries Conservation at Ardnacrusha and Parteen is presented in an addendum to this report in Appendix B. The findings of this assessment supersede those in the original 2016 review in relation to salmon migration. The summary conclusion is as follows:

- Over the past 40-50 years there has been a dramatic decline in the numbers of salmon returning to rivers on both sides of the north Atlantic and that is reflected also in the ESB's records for salmon on the River Shannon. Furthermore, the number reaching the West Offaly Power Station in Shannon bridge, some 78km upstream of the

Ardnacrusha hydro station, is likely to be only a small proportion of the on-average 2000 or fewer salmon that return on an annual basis currently, as the majority enter tributaries farther downstream to spawn. Records available for recent years suggest that on average about 35% of all the salmon that escape into the system upstream of the dam do so in the months of June and July and it is likely that only a portion of these salmon are likely to encounter temperatures at WOP that could delay their upstream migration. Indeed, an analysis of the continuous temperature data for this period in 2017, would suggest that in 2017 none of the salmon reaching the WOP reach would have been delayed in their upriver migration. This assumption is based on a review of the published literature on the species thermal tolerance both in the field and in laboratory studies and the assumption that migrating salmon would choose to follow the coolest track through the temperature-affected reach at WOP.

- Returning smolts could be at some risk, although one that is less easy to quantify due to the absence of data on the numbers likely to be migrating down through the WOP section of the river. It is believed that in most years by the time temperatures would be high enough to cause the smolts temperature-related difficulty, namely in the form of impaired swimming performance, most of the population would likely have already migrated past this point in the river. Moreover, the significant distance of the site from the sea might also mean that the majority of the smolts would have started to migrate before May, when the 2017 temperature record showed that there were short periods when temperatures were high enough (i.e. ~20°C) to reduce the swimming ability of smolts at WOP, thereby slowing their passage through the affected ~1-1.5km of river, which in turn might make them more susceptible to predation by pike or perhaps avian predators also. Overall, taking into account the available data on temperature for the site as well as its location, it is considered that the risk to smolts due to the WOP thermal discharge is more likely to be on minor than a moderate scale at the population level.

6 Diatoms

Diatoms were collected from macrophytes for analysis at 8 sites from WOP respectively in 2014 and from 10 sites in 2015 and in 2016 (see Figure 6-1 for the 2015 and 2016 positions). These collections were analysed for TDI (Trophic Diatom Index) which in turn is used to generate EQR (Ecological Quality Ratio) which determines the WFD (Water Framework Directive) Ecological Status of a given site. Each diatom collection usually contains quite a diverse range of species, several of which tend to be found at the majority of sites. Among these, a smaller number may be well represented at most sites and therefore have the potential to have greater indicator value. *Achnanthidium minutissimum* is such a species and as part of the data analysis, trends in this species were examined at WOP as they seemed to respond to the temperature variations at the site. Overall species diversity also appeared to be more or less responsive to the temperature at each site and it was also assessed in order to discern a temperature effect.

6.1 General Trends

In terms of TDI and hence EQR and WDF Status, sites upstream of the thermal discharge tended to have Good or High Status which dropped to Good or Moderate in the stretch immediately below the thermal discharge before recovering to Good or High Status some distance downstream (Table 6-1). The distance downstream required to regain the same Good or High Status as upstream from the discharge varied between years. In 2014, Good Status was regained from between 184m to 218m (i.e. by Site 5d/s). In 2015 High Status, which was present immediately upstream of the discharge, was regained within about 101m downstream, i.e. by Site 4d/s, but reverted again to Good (from High) at Site 5d/s, a site although farther from the discharge than Site 4d/s had a higher temperature. EQR returned again to High Status at Site 6d/s i.e. 184m downstream of the discharge. In 2016, High Status, which pertained immediately upstream of the thermal discharge, was regained by Site 6d/s. In all years therefore, the status pertaining immediately upstream of the thermal discharge in each year was regained at most within 218m downstream of the discharge i.e. by Site 6d/s. This indicates a short zone of influence at WOP. Moreover, it would appear than in the case of diatoms at least, the background (i.e. upstream) quality status tends to be more High than Good at WOP.

Figure 6-1 Aerial view of WOP stretch showing 2015 & 2016 biological survey locations

One of the most numerous diatom species collected at both study sites was *Achnanthidium minutissimum*. This species is recognised to be a prominent diatom at Good and High Status sites. In WOP surveys, its proportional abundance either as a percentage or a fraction of the diatom sample at each site was negatively correlated with temperature, being high at upstream sites and much lower at those sites downstream of the discharge experiencing more elevated temperatures. This is illustrated in the following two graphs (Figure 6-2 and Figure 6-3). The first graph (Figure 6-2) shows the sharp drop in the relative abundance of the species at sites immediately downstream of the discharge followed by a gradual recovery with distance downstream as the temperature drops. This temperature effect is further demonstrated by comparing the normalised temperature at each site with the proportion of the species at that site (Figure 6-3). This shows the inverse relationship between temperature and the proportions of the diatom.

6.2 Another possible diatom indicator species

Although TDI is based on a whole community analysis, we have seen by examining the trends in occurrence of a single species namely, *A. minutissimum*, that diatoms may also provide valuable indicator information at the level of individual species. This possibility prompted a further examination of the diatom species data from WOP for other frequently encountered species that might also act as indicators. This exercise revealed that another diatom *Cocconeis placentula* var *euglypta* was present at most stations both upstream and downstream of the discharge and in both 2015 and 2016. Unlike *A. minutissimum*, *C. placentula* var *euglypta* increases in abundance at sites with warmer temperatures. In fact, the 2 species had a pronounced inverse relationship at the WOP sites in both 2015 and 2016. This effect is in keeping with the published literature where *Cocconeis placentula* var *euglypta* has been described as a thermophilic species being a dominant community member in streams downstream of warm water spring discharges and in the discharge canal of a power station. The relationship between the two species is evident at the WOP sites but the trend related to temperature differential is not significantly evident, especially in 2015 and consequently this species has less value as an indicator species but could nevertheless provide some corroboratory information.

6.3 Summary

The 2014, 2015 and 2016 surveys have all shown clear trends in various diatom metrics at WOP influenced by the thermal plume. The effect at WOP was confined to within about 430m in 2014. In 2015 and 2016, when water levels were higher, the effect was generally shorter in extent, stretching to less than 200m downstream of the thermal discharge.

In the case of the West Offaly Power biological surveys, diatoms offer many advantages over both macrophytes and macroinvertebrates as a monitoring tool:

(i) They are very easily collected without the need for specialised sampling equipment from macrophytes growing at the sites,

(ii) They are not impacted by issues of substrate or light penetration, which have a very significant effect on invertebrates and macrophytes which as a result can be spatially very patchy and

(iii) They also have a much shorter generation time and therefore reflect fairly recent changes in the environment compared to either macrophytes or macroinvertebrates.

(iv) Site		Ecological Status		
2014	2015/2016	2014	2015	2016
	1u/s	H	H	H
1u/s		G		
2u/s		G		
3u/s	2u/s	G	H	H
	3d/s		M	G
	4d/s		H	G
4d/s	5d/s	M	G	G
	6d/s		H	H
5d/s	7d/s	G	H	H
	8d/s		H	H
6d/s	9d/s	G	H	H
7d/s		H		
8d/s		H		
	10d/s		H	H

Table 6-1 Diatom determined ecological status at WOP sites 2014-2016

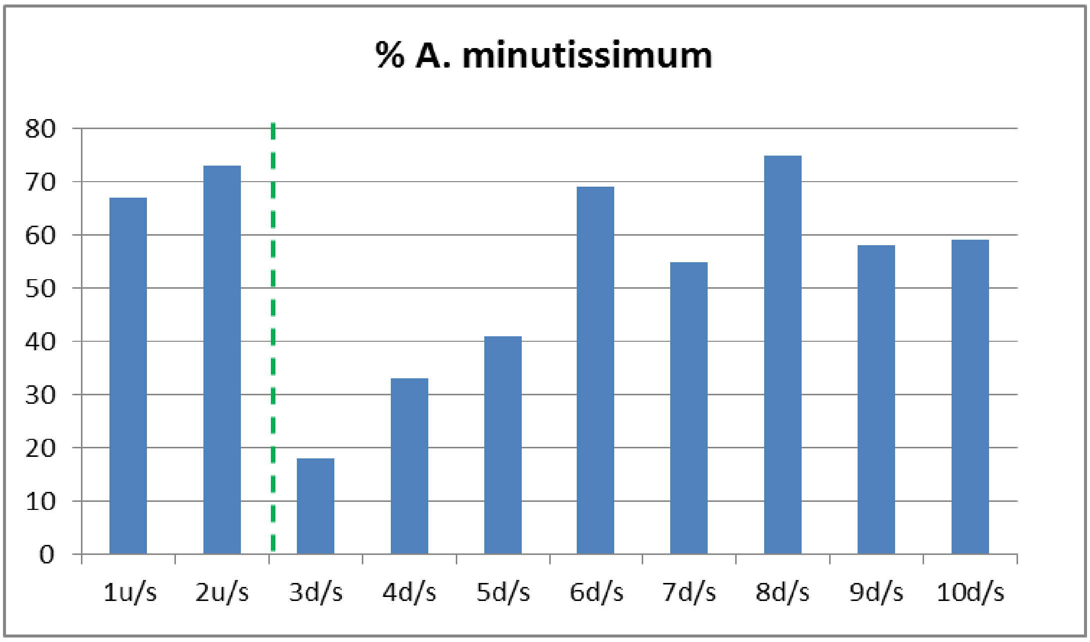


Figure 6-2 WOP 2016- Relative abundance of *A. minutissimum* in relation to thermal outfall (green dashed line)

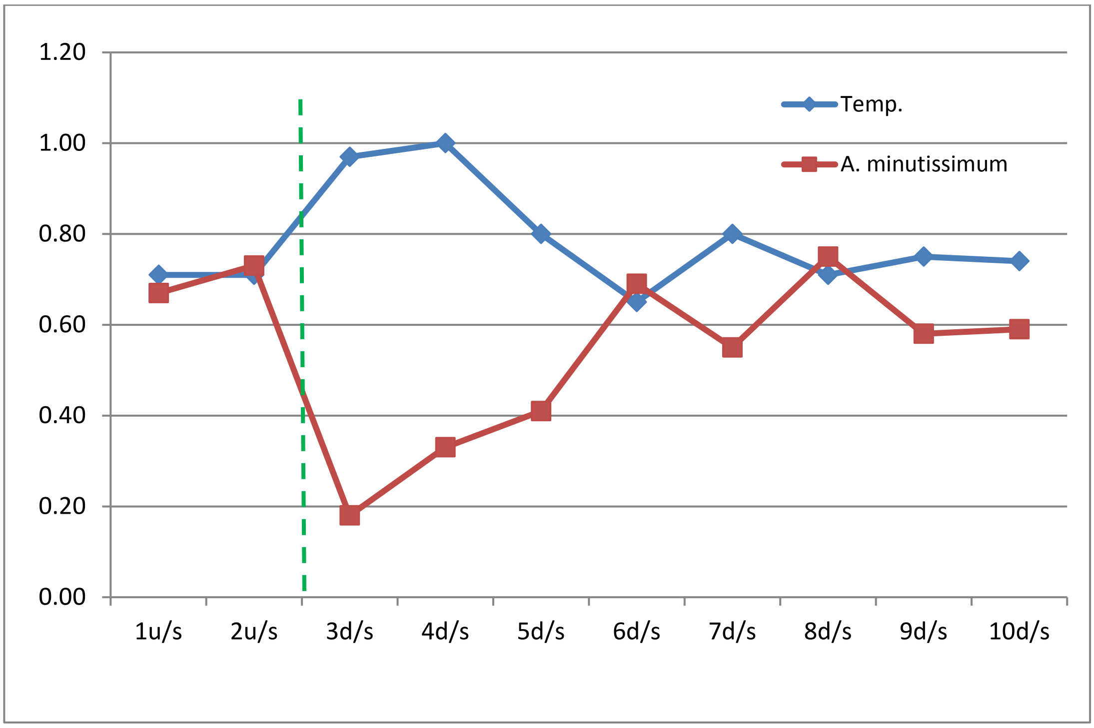


Figure 6-3 WOP 2016 Relative abundance *A. minutissimum* vs temperature (normalised), thermal outfall = green dashed line

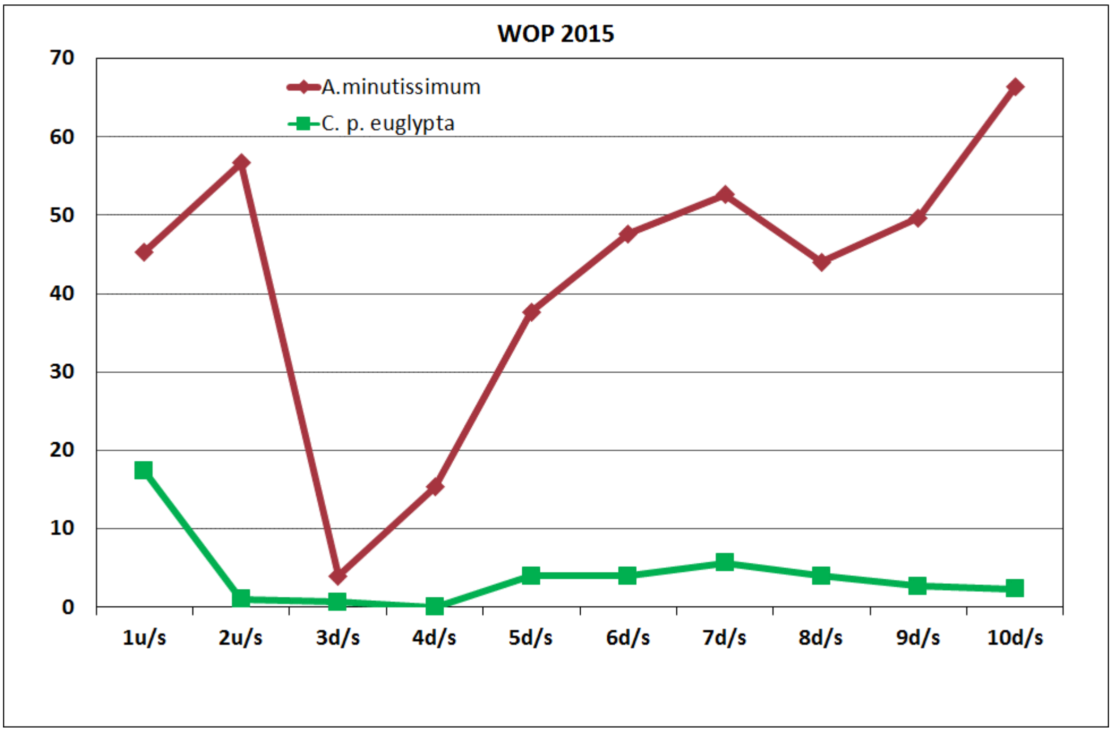


Figure 6-4 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at WOP sites in 2015

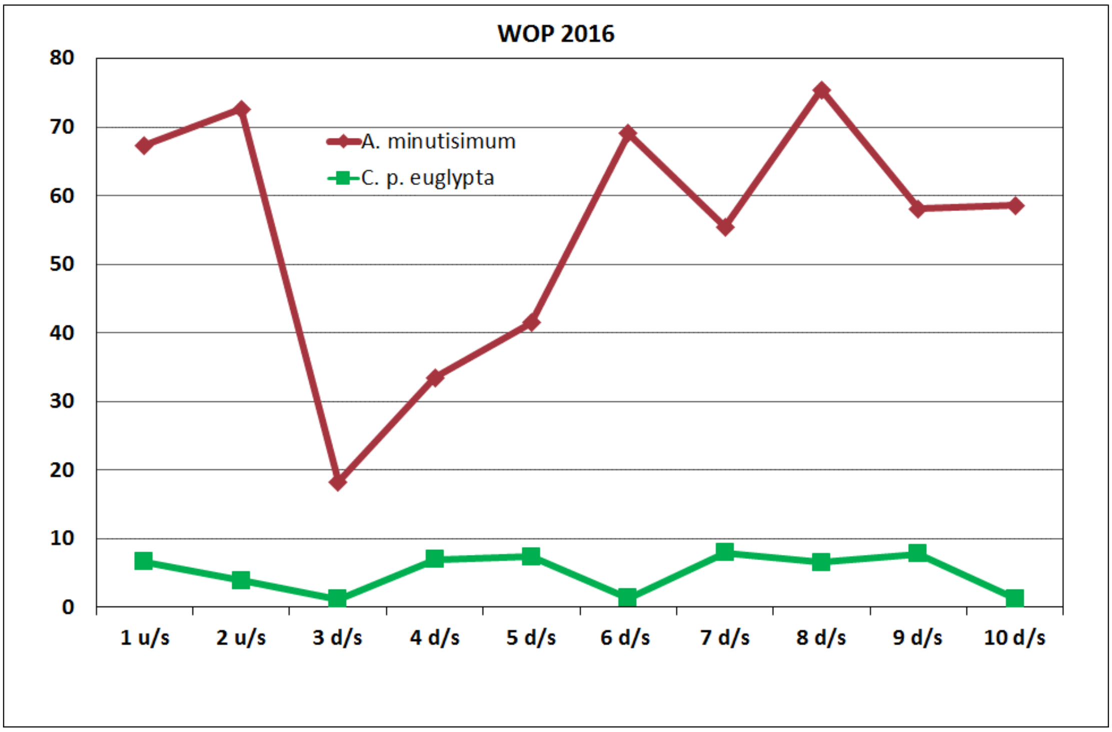


Figure 6-5 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at WOP sites in 2016

7 Macrophytes

Aquatic macrophytes were sampled by ASU in each of the three annual monitoring events in August 2014, 2015 and 2016 along with observations on macroalgal cover and freshwater sponge. The surveys comprised percentage cover assessment of 2 to 5 quadrats along transects of variable lengths, one at each sampling site. The precise length of each transect as well as the number of transects along varied between years depending on the water levels in the river at the time. In all 3 sampling events, the photic zone seemed only to penetrate to about 2m, below which no plants were present.

The macrophytes were represented by a limited list of species, the majority of which are very common in lowland rivers in Ireland which are also quite common in fairly eutrophic conditions. They can therefore be described as tolerant species in the wider sense. They included:

Higher Plants

- *Phragmites australis*
- *Schoeloplectus lacustris*
- *Equisetum fluviatile*
- *Sparganium erectum,*
- *S. emersum*
- *Eleochris palustris*
- *Alisma lanceolata*
- *Myriophyllum spicatum*
- *Nuphar lutea*
- *Saggitaria saggitifolia*
- *Potamogeton perfoliatus*
- *P. crispus*
- *P. lucens*
- *P. friesii*
- *Mentha aquática*
- *Berula erecta*
- *Oenanthe crocata*
- *Zanichellia palustris*
- *Eleodea canadensis*
- *Carex sp.*

Mosses

- *Fontinalis antipyretica*

Algae

- Blue-green algal mats
- *Thorea hispida*
- *Cladophora*

Freshwater sponge

The distribution and cover values of the vast majority of these plants depended on factors such as substrate type, depth and flow and in general could not be linked in any obvious way to the thermal discharge. The only exceptions to this were the red alga *Thorea hispida* and aquatic sponges. The algae is relatively exotic and while it is know from Britain in larger rivers, this seems to be the first record of this very distinctive species in Ireland. It was prominent in 2015 and 2016 in the warm water side of the Shannon at WOP and this would appear to be the only definitely discernible feature of the macrophyte data that points to a thermal effect. A recent review of the species indicates that it is a much more tolerant species than originally believed (Bolpagni *et al.,* 2014) and can tolerate highly eutrophic conditions. Most of the records tend to be from warmer countries as well as from larger and deeper channels. The species seems also to be more widespread than initially believed and the lack of records to date may well be related to its deeper preferences and the lack of systematic searches up until recently as part of algal monitoring programmes associated with the WFD. *T. hispida* was not noted upstream of the thermal discharge in any of the 3 years (2014-2016). However, it was very prominent in some quadrats downstream decreasing in abundance with distance downstream. Its highest % cover was 50% in the first quadrat at site 3 d/s i.e. just 21m downstream of the thermal discharge (2016). Beyond ~200m downstream it wasn't recorded again in amounts greater than 1% in 2015 and 2016. It fared best in quadrats where higher plants were generally scarce. Overall it seems to be a good indicator of impact within the first 100-200m of the thermal outfall (possibly farther in very low flow years during summer) and in this respect acts as a complimentary indicator to diatoms whose zone of effect is similar.

Blue green algal mats were prominent especially at the deeper quadrats over cobble/gravel substrate. However, this was also the case upstream in certain quadrats, so that as a group, they have very limited indicator value at this site. However, where *Thorea hispida* was prominent, tufts of wispy blue green algal mats were also prominent and it possible that a more focused examination could reveal particular species that are good thermal indicators. This notwithstanding, this group can be extremely difficult to identify to species level and also shows a high degree of morphological variation even within the same species making it a less than ideal group for such work.

Freshwater sponge was noted to be present as a luxuriant growth form at Shannonbridge not typical of the species in general but also noted during the equivalent surveys at Lough Ree Power, which was surveyed within days of WOP during 2014, 2015 and 1016 biological surveys. However, its low cover values reduce it's value as a good indicator species at WOP, even though the growth form observations may still be useful when taken in conjunction with other indicators.

8 Macroinvertebrates

Macroinvertebrates were sampled at seven six sites in 2014 and at ten sites in 2015 and 2016 using a small van veen grab (2014) and a dredge (2015 and 2016).

The dominant species at all sites were typical of EPA Class C, D, and E invertebrates i.e. typical of moderate, poor or bad status waters, with far fewer species and individuals in the A and B classes i.e. species more typical of high and good status waters. The most numerous species were invasive species including the zebra mussels (*Dreissena polymorpha*) and a small crustacean (*Chelicorophium curvispinum*), a rare species in Ireland. Other frequently encountered species, were *Asellus* and *Gammarus*, chironomidae, oligochaetes, and flat worms. A variety of other species from several other groups were also present, generally in smaller numbers including the invasive bivalve *Corbicula fluminea* (Asian clam), molluscs *Theodoxus fluviatilis*, *Bithynia tentaculata* and *Potamopyrgus jenkinsi*, the cased caddis *Ceraclea* spp, and several other taxa normally only present in very small numbers.

In none of the 3 years monitoring was it possible to detect any definite thermal-related effect in the samples collected. The evidence for a thermal influence on the Asian clam which was noted at Lanesborough in an IFI study in 2014 (Caffrey & Millane, 2014) and supported by the recording of high densities of the species downstream of Lough Ree Power (LRP) in the 2014-2016 biological surveys at that location was much less in evidence at WOP. The clam was present in moderate to higher densities just below the discharge at sites 3 d/s to 5 d/s (2015 and 2016) i.e. within 160m, however, farther downstream numbers were much lower and patchy.

Patterns of distribution of two of the most common species present appeared to show a slight temperature effect. *Chelicorophium curvispinum* and zebra mussels were least dense at the warmest site i.e. 3 d/s in both 2015 and 2016. However, Lucy et al. (2004) notes that *Chelicorophium curvispinum* appears to be strongly associated with zebra mussels in Ireland. Its distribution therefore seems to be more dependent on the presence of the mussels than any particular temperature preferences. Zebra mussels themselves tend to prefer hard substrates on which to attach, as well as more sluggish flows, which in turn may also be the greater determining factors in their observed distribution. However, a temperature effect on zebra mussels and *Chelicorophium* cannot be entirely ruled out at this stage, especially at 3 d/s, although a more targeted approach would probably be required to rule this relationship in or out. However, neither species appear to be a sensitive temperature indicator.

None of the less dominant species showed any discernible or consistent distribution pattern that could be attributed to temperature effects. It is possible that with continued annual sampling at the same sites over several years that a pattern might emerge in some cases. However, given that the numbers in the case of these latter species tend to be low, there is no guarantee that such a pattern would emerge and its value in any case would arguably be of lesser ecological significance, given the lower densities involved.

Overall, monitoring using macroinvertebrates at WOP has only very weak indicator value. This may be because the majority of species and individuals both in the cooler and warmer stretches are already quite tolerant and are less sensitive to environmental stress. Furthermore, the localised variability in substrate and flow may also be helping to mask a thermal effect. In addition, the relatively confined extent of elevated temperatures downstream of the thermal discharge may also be a factor.

9 Assessment of acceptability of thermal plume mixing zone at WOP

The European Communities Technical Guidance (Technical Guidelines for the Identification of Mixing Zones pursuant to Art. 4(4) of the Directive 2008/105/EC) has been followed to assess the acceptability of the thermal plume mixing zone in the Shannon River at WOP.

The Water Framework Directive implementing strategy is underpinned by ensuring compliance with environmental quality standards (EQS) and effluent discharge control regimes are normally designed to ensure that concentrations of polluting substances in the receiving water do not exceed the EQS. However, if the concentration of the contaminant of concern (CoC), heat in this case, in the effluent is greater than the EQS value at the point of discharge there will be a zone of EQS exceedance in the vicinity of the point of discharge. Directive 2008/105/EC allows Member States to permit such zones of exceedance in water bodies when a number of criteria are met. Understanding these is important as it enables the Competent Authority first to identify whether this level of exceedance is acceptable for a proposed mixing zone and then to identify the appropriate location for monitoring points.

The Technical Guidance on the establishment of mixing zones for substances listed in Annex I of the Environmental Quality Standards of Directive 2008/105/EC underpins the Water Framework Directive implementing strategy through ensuring compliance. Although not directly applicable to the thermal cooling water discharge at WOP, where the issue is “heat” for which an EQS has been set by the EPA, the principle of the technical guidance to establish the mixing zone can be applied. It should be noted that the ultimate fate of heat is loss to the air as opposed to Annex I substances, hence the potential impact is confined to the thermal plume footprint and is not persistent.

The Technical Guidance sets out a tiered approach to identifying a relevant mixing zone but it does include several caveats that must also be evaluated in any assessment. These relate to:

- The application of Best Available Techniques as the thermal discharges are regulated under Industrial Emission Licences. The applicable Best Available Technique (BAT) to energy efficiency and industrial cooling systems must be applied to ensure that any potential changes to cooling water regime or plant operation are appropriate and not disproportionate in terms of cost and environmental benefit gained.
- The requirements of Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (the EU Water Framework Directive (WFD)) must be adhered to in establishing an appropriate mixing zone. The EQS standard does recognise the need to develop a mixing zone outside of which the substance, heat in this case, does not affect the compliance of the rest of the water body with its status requirements into which for example the thermal cooling water load is discharged. The objectives and measures set out in the River Basin Management Plan must also be adhered to and must not be compromised by the mixing zone.

- The requirement to adhere to the thermal conditions set out in Directive 2006/44/EC on the quality of freshwaters to support or enhance fish life. In the case of WOP, the key question to be answered is whether the mixing zone will constitute a significant impact to fish in terms of migration or overall population.

An assessment of the applicability of the EU Technical Guidance for the identification of mixing zones at WOP (and also at LRP) has been carried out and is provided in the separate ESB International report, "Identification of mixing zones to Lough Ree Power and West Offaly Power" {Reference 28] . The assessment assumes that thermal heat can be considered as a contaminant of concern within the receiving water and, as such, the principle of applying a mixing zone as set out in Technical Guidance is appropriate for both LRP and WOP

The tiered approach to assessment of the acceptability of the thermal plume was progressed with significant in river bathymetric and thermal assessments carried out since 2014 allowing identification of the extent of the thermal plume and actual mixing zone to be determined under varying climatic conditions.

The in river monitoring also included aquatic ecology and fish assessments which indicate that a localised impact is present but the thermal plume discharges do not effect the overall river water body status into which the thermal plume discharges occur.

Accompanying this was a literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the study areas concerned and a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. The current review and risk assessment would suggest that the thermal discharge at WOP is likely to have only minor impacts on the resident fish community. Neither the potential impacts on adults nor those on smolts are likely to result in a significant negative impacts at the population level.

A more specific assessment of the potential impact on migrating salmon (adults and smolts), based on an analysis of the continuous (5-minute) river temperature monitoring from July 2016 to December 2017 combined with more recent adult salmon census data from Ardnacrusha and Parteen (see Addendum in Appendix B) concluded that none of the salmon reaching the WOP reach would have been delayed in their upriver migration. This assumption is based on a review of the published literature on the species thermal tolerance both in the field and in laboratory studies and the assumption that migrating salmon would choose to follow the coolest track through the temperature-affected reach at WOP. Additionally, it is considered that the risk to smolts due to WOP is more likely to be more minor than moderate in scale at the population level.

10 Conclusions

10.1 Thermal plume surveys

Four thermal plume surveys of the River Shannon at West Offaly Power in Shannonbridge since July 2014 and continuous temperature monitoring from seven locations since July 2016 have been reviewed.

The EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26028) at Shannonbridge as a reference indicator of flow conditions in the Shannon at West Offaly Power.

Based on data and observations to date the following conclusions can be made:

- Two of the thermal plume surveys were carried out during high Shannon flows in February and November 2015. These showed that the thermal plume resulting from the thermal discharge from West Offaly Power is very small. The other two surveys were carried out during medium and low flow conditions in July 2014 and May 2016. The station was in breach of Condition 5.5 of the IEL licence for the July 2014 survey when Shannon levels were low and was not in breach of Condition 5.5 of the IEL licence during the May 2016 when levels were medium.

- During medium to high flows in the River Shannon, the thermal plume from the thermal discharge of West Offaly Power is small with respect to the river cross-section area.
- The thermal plume increases in size as levels and flows in the river Shannon decrease.
- The thermal plume discharge from West Offaly Power Station can potentially extend across the entire river channel when the water level at the gauge at Shannonbridge reference hydrometric gauge falls below approximately 2.4 m. The OPW long term assessment of the gauge gives the 50 percentile level as 2.972 m.
- Below approximately 2.25 m at Shannonbridge reference hydrometric gauge, the thermal plume from West Offaly Power will likely extend across the river channel under all meteorological conditions and vegetation growth.
- Data from the continuous temperature monitoring programme does substantially verify the results of the thermal plume surveys.
- It is not possible to accurately determine the cross sectional area of the thermal plume from the continuous temperature monitoring at seven locations. Nevertheless, at very low river levels, it can be inferred from the continuous temperature data that the thermal plume is present across the river channel. There is evidence of the simultaneous presence of thermal plume at all monitoring locations on a number of occasions.

10.2 Fish

The results of the fyke net surveys demonstrate that, on the dates surveyed, the fish communities present at WOP are typical of that part of the Shannon as determined by previous IFI surveys reported to date and were dominated by cyprinid fish species.

The detailed analysis of catches in nets on the cooler and warmer sides of the channel, indicates that none of the species recorded as more than a single specimen was excluded from the warmer part of the channel at WOP during any season.

The absence of trout at WOP (and also at LRP) during August 2016 mirrors the findings of IFI surveys on the main channel in 2010 and 2016 and may be a seasonal effect in the Shannon in general rather than a reflection of any thermal stress derived from the thermal discharges. This is suggested because the 2016 IFI survey undertaken at 23 sites on the main channel from mid to upper Shannon, didn't return a single trout.

Some species, seem to show at least a mild preference for the cooler or warmer sides of the channel depending on the season but the evidence from the survey isn't very strong for any species.

Overall, based on the data available from the fyke net surveys and the previous IFI surveys, there is no clear evidence that the thermal discharge is having an adverse impact on the resident fish community at WOP. This isn't to say that there may not be subtle effects at the level of individuals within the population that for example may be stimulated to spawn earlier or perhaps grow faster but such changes would be probably not be possible to detect using normal survey methods. This finding is in keeping with more extensive examinations into the impact of thermal discharges on fish communities undertaken in France (Daufresne and Boet, 2007)

It is likely that the fyke net results obtained reflect the normal average year in the system, i.e. not very low water levels and not extreme temperatures. A repeat survey during high temperatures combined with low flows might reveal somewhat different trends.

In addition the literature survey and risk assessment of potential impacts on migratory fish species present in the system indicates that no significant impact is likely to occur.

10.3 Diatoms

Diatoms were the only survey technique that clearly and unambiguously demonstrated a biological effect from the thermal discharge at WOP. In 2014, when the river was at its lowest, the diatom community showed an effect for 430 m downstream, whereas in 2015 and 2016 when the flows were higher, the effect was detected for just 200 m downstream.

Diatoms have much to recommend them as a monitoring tool including ease of sampling and proven effectiveness in all surveys to date.

10.4 Macrophytes

The use of macrophytes for monitoring the thermal impact at WOP (and also at LRP) has provided very little useful information in detecting a thermal influence. The only exception to this was the presence of the red macro alga (*Thorea hispida*) which was clearly promoted at WOP by the presence of the thermal discharge. Indeed it could be said at that site to have had a similar indicator value as diatoms. The presence of locally high concentrations of 'tufted' bluegreen algae at the same sites where *T. hispida* was also prominent, would suggest that this group may have some value also as an indicator, although taxonomic identification may be difficult. The presence of unusual and luxuriant growth forms of freshwater sponge within the thermal discharge was the only other aspect of the macrophyte survey effort that provided evidence of a thermal response. Although the low cover and patchy distribution of the sponge makes it less powerful as an indicator by itself. Overall, the general tolerance of the existing plant community combined with the heavy influence of hydromorphology on that community (substrate, flow and depth/light) means that the general macrophyte community at this site, apart from the exceptions referred to above, is unlikely to provide any useful monitoring information.

10.5 Macroinvertebrates

The macroinvertebrate community at WOP is characterised by species tolerant or very tolerant of impaired water quality. Moreover, the community is overwhelmingly dominated numerically by a small number of invasive species two of which are major ecosystem-altering species namely zebra mussels and Asian clams, the latter only recently arrived and still expanding its range. Like macrophytes, the importance of hydromorphological factors including substrate and flow in particular seems to be the main factors determining the nature of the very patchy invertebrate community at any given site and because of that any thermal effects are either not occurring or are masked by these other factors. Some temperature related trends were noted for species such as the crustacean *Chelicorophium curvispinum* and zebra mussels but it wasn't possible to conclusively rule out substrate preferences as factors giving rise to this apparent effect. Overall, however, macroinvertebrates are fairly poor indicators of a thermal effect at WOP.

11 Overall Conclusion

ESBI has followed the Technical Guidance on mixing zone determinations and the following conclusions can be drawn:

- Thermal cooling water discharges have occurred to the Shannon River at Shannonbridge since the late 1950's when electricity generating stations utilising peat as a fuel were first constructed. Shannonbridge Generating Station was decommissioned in 2003 and its associated Integrated Pollution Control Licence (No. P0626-01) was surrendered in 2011.
- West Offaly Power Generating Station was first licenced under Licence No. P0611-01 in 2002. Although the licence contained conditions relating to water temperature outside of the mixing zone no definition of the mixing zone was included until the new Licence (IEL No. P0611-02) was issued in 2013.
- Thermal heat could be considered as a contaminant of concern within the receiving water and as such, the principle of applying a mixing zone as set out in Technical Guidance is appropriate for WOP.
- The tiered approach to assessment of the acceptability of the thermal plume was progressed with significant in river bathymetric and thermal assessments carried out since 2014 allowing identification of the extent of the thermal plume and actual mixing zone to be determined under varying climatic conditions.
- The current WFD status of the river water body into which WOP discharges thermal cooling water is "Unassigned"
- An assessment of the ecological impact of the thermal plume discharges in terms of impact on macrophytes, macroinvertebrates and diatoms was carried out in 2014, 2015 and 2016 which identified that diatoms were the most reliable assessment species. The ecological impact assessment identified that an impact does occur but that this is within the thermal plume actual mixing zone with the "status" returning to at least Good within 200-400m of the discharge location. The thermal plume impact does not effect the status of the rest of the water body length and is localised in effect.
- An important issue for the acceptability of a mixing zone is that of potential impact on fish migration and river connectivity for fish which is a key objective of the Draft RBMP for Ireland 2018 – 2021. Fish sampling undertaken by IFI and ESB has identified the key fish species present in the system at WOP. A literature review and risk assessment relating to thermal plume potential impacts as barriers to migratory fish has been completed which concludes that there is no clear evidence that the thermal discharges are having an adverse impact on the resident fish community at WOP.
- WOP operates within the LCP Bref and Industrial Cooling Water Bref and is BAT compliant with respect to cooling technology (once through and nett energy efficiency). Any additional requirement such as mechanical cooling would likely reduce energy efficiency, would entail significant cost and, based on the ecological impact assessment to date, would not significantly enhance the achievement of water quality status requirements under the WFD. The cost would be disproportionate to any environmental benefit that could be achieved.

In conclusion and following the Technical Guidance approach on mixing zones and ecological and fish assessments undertaken to date, a review of the allowable in river extent of the thermal cooling water mixing zone for compliance purposes should be undertaken given that no overall significant impact on the receiving water bodies occurs into which the thermal discharges take place. Larger mixing zones reflecting the actual thermal mixing zones can be defined for West Offaly Power which should be acceptable in terms of the WFD requirements.

12 Recommendations

The following are the main recommendations with respect to the thermal cooling water discharge from WOP;

- Maintain the programme of continuous temperature monitoring. Download and issue reports on a monthly basis.
- Upgrade temperature recording system to facilitate the transmission of data to a central storage facility.
    - Continue to issue reports on a monthly basis
- Identify and log periods of non-compliance with Clause 5.5

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Appendix A.

Graphical Information Referenced in Main Report

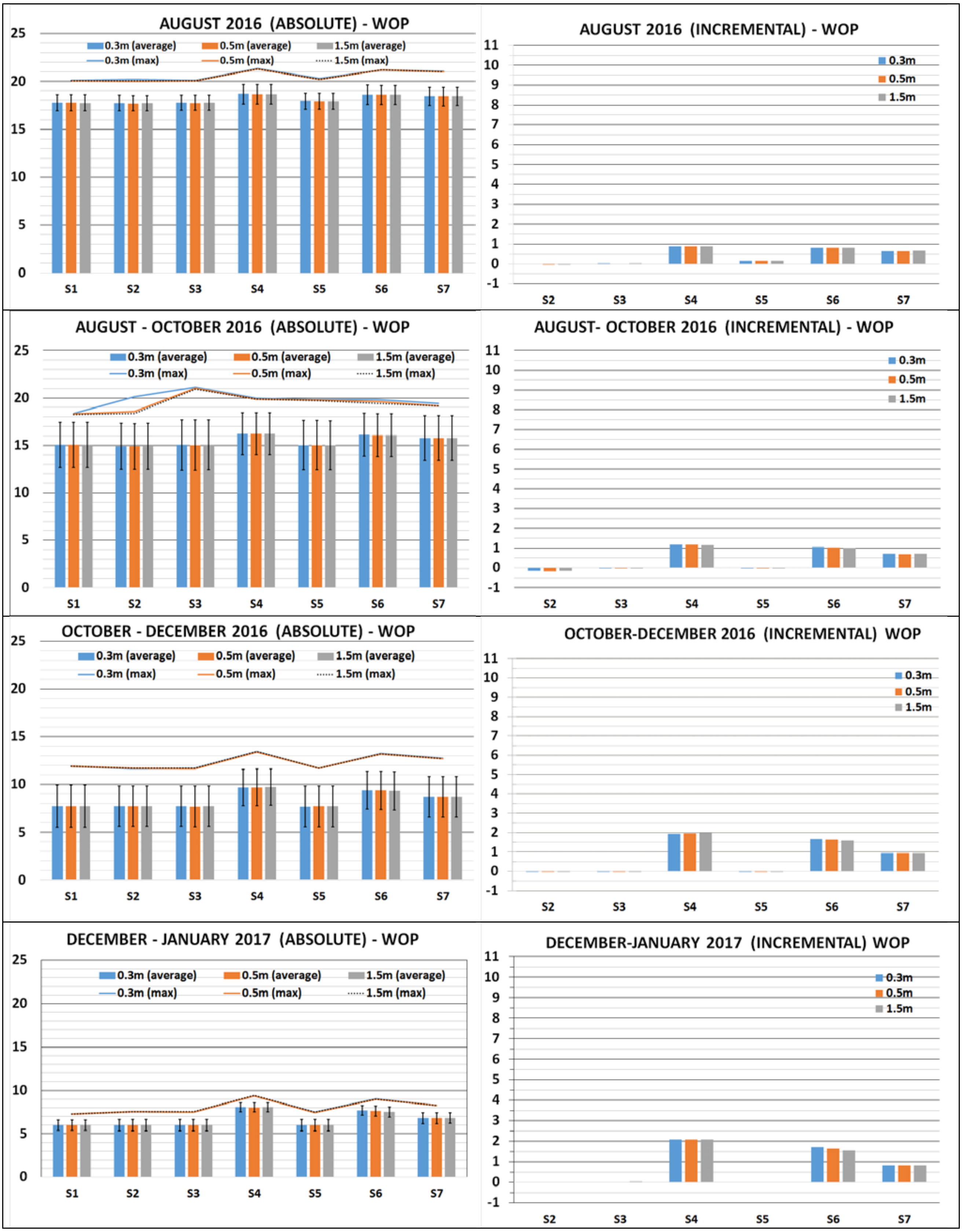


Figure A-1. Summary temperature data at WOP in degrees Celsius (°C) from the monthly continuous in-river monitoring from July 2016 to December 2017*.

*Graphs on the left depict average absolute temperatures (with error bars indicating Standard Deviation) at 0.3m, 0.5m and 1.5m depth stations at each of the 7 sites. The right side graphs represent the average incremental increase in temperature at each site when the average temperature at Site 1 i.e. upstream of the thermal discharge is subtracted from the average temperature at the corresponding depths at each downstream site. Data from Irish Hydrodata monitoring.

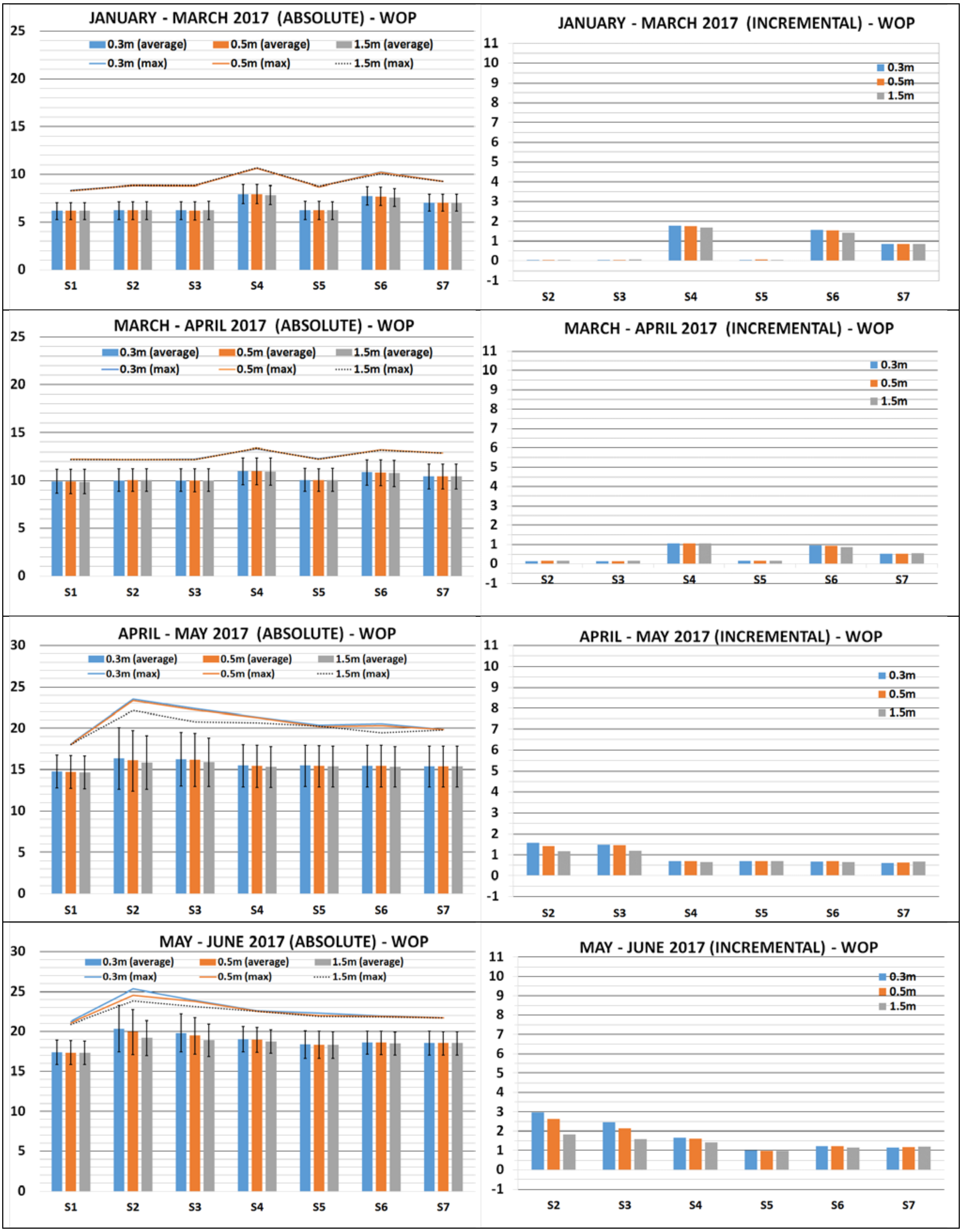
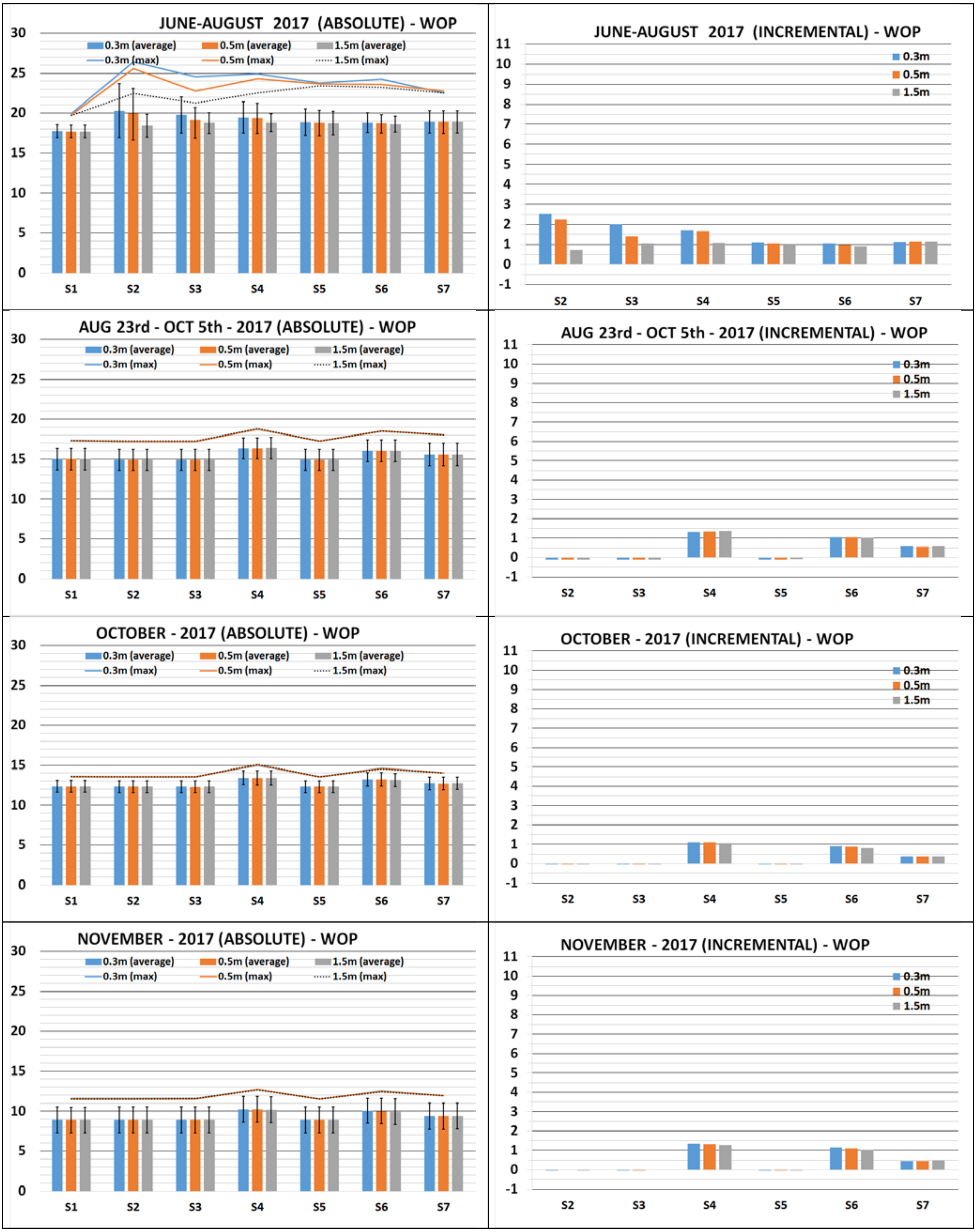


Figure A-1 (contd.)



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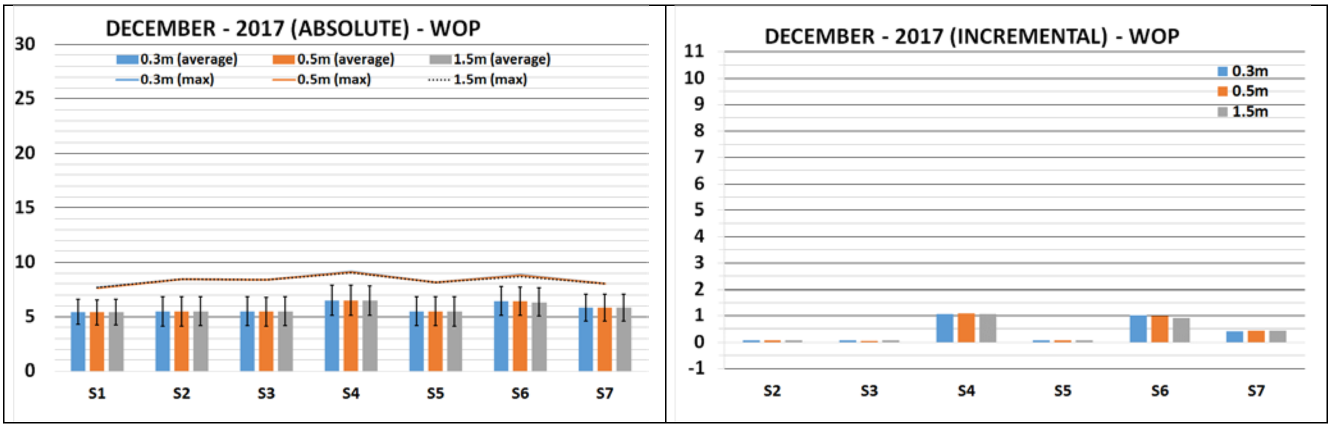

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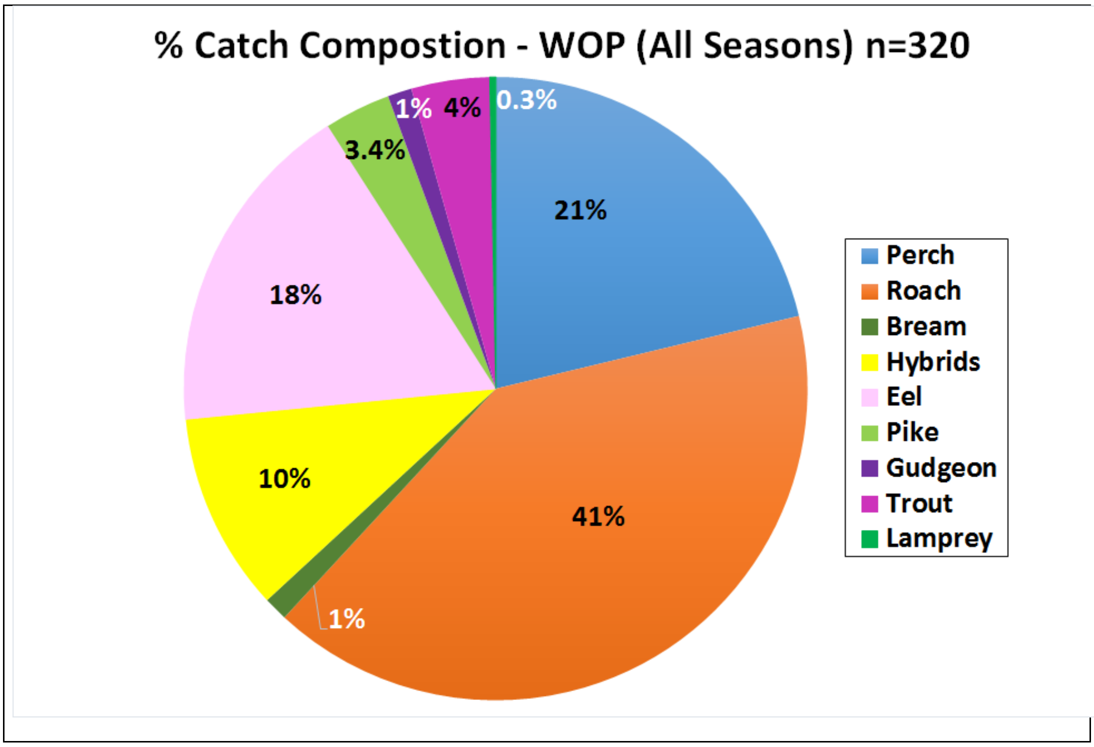

Figure A-2: Proportional composition of the total number of fish caught in all 5 surveys at WOP (2016-2017)

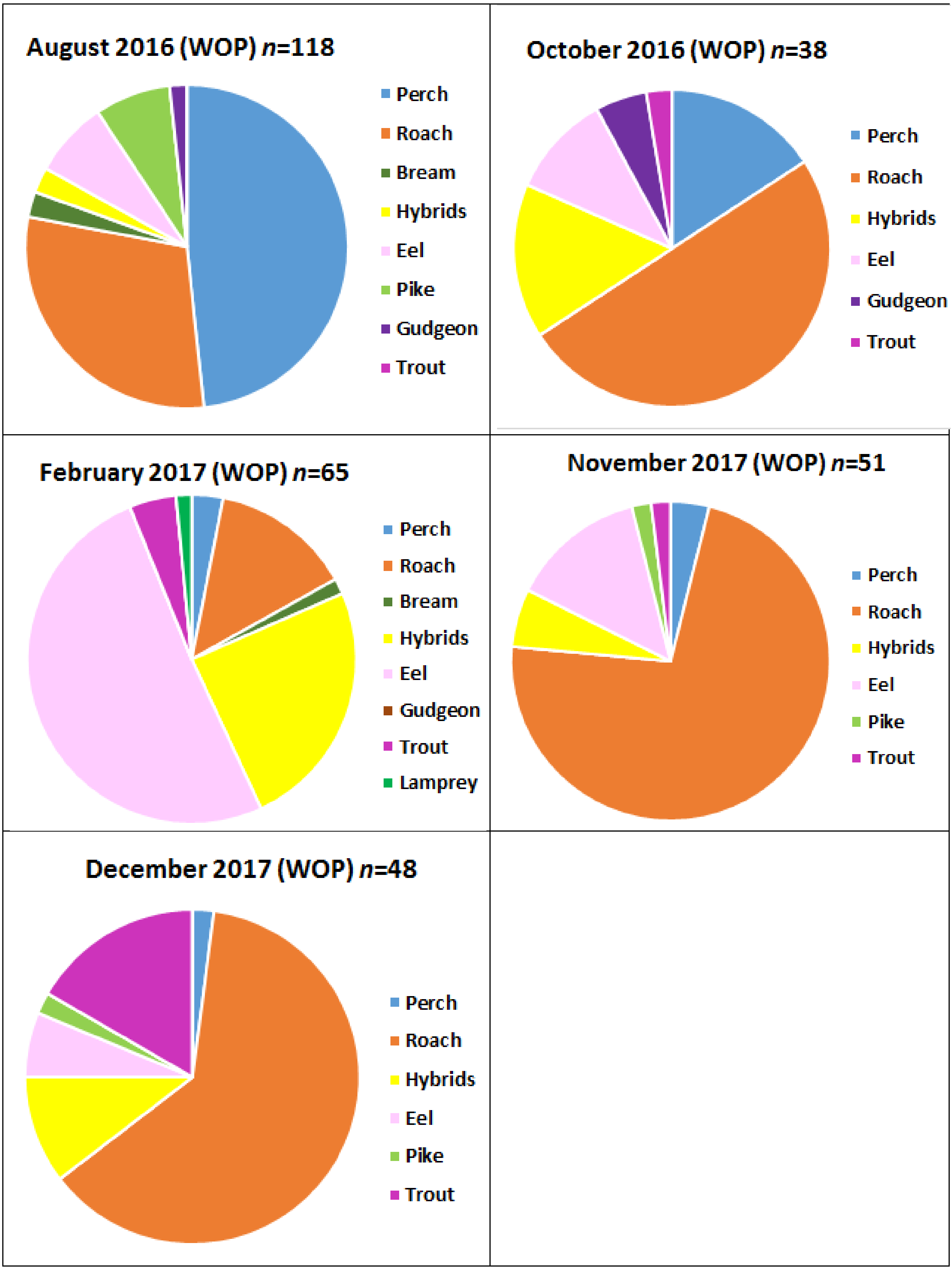

Figure A-3: Pie charts showing the proportional composition of each species taken in each of 5 fyke net surveys in WOP (August & October 2016 and February, November and December 2017)

Appendix B.

Aquatic Services Unit Literature Review of Potential Fisheries Impacts – Documentation

- **Shannon Power Stations Literature Review of Potential Fisheries Impacts (July 2016)**
- **Response to EPA Observations on: Shannon Power Stations Literature. Review of Potential Fisheries Impacts (July 2016). September 2016**
- **Atlantic salmon temperature tolerance - Addendum to Literature Review - WOP**

Shannon Power Stations Literature Review of Potential Fisheries Impacts

(July 2016)

Commissioned by: ESB International

Carried out by: Aquatic Services Unit (UCC)

(July 2016)

Contents

Introduction

The Environmental Protection Agency (EPA) requested that the potential for impact on fisheries in the River Shannon of the cooling water discharges from Lough Ree Power (LRP) and West Offaly Power (WOP) power stations should be assessed. In part fulfilment of this condition, the client, ESB Generation & Wholesale Markets, agreed to undertake a literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the study areas concerned and to undertake a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. This report presents the findings of that review and risk assessment, which was undertaken by Gerard Morgan M.Sc. of the Aquatic Services Unit.

Study Approach

In undertaking the review, temperature data provided by the client for both sites (LRP and WOP) were analysed and compared with the thermal sensitivities of the fish community resident or migrating through both sites. The temperature data in question comprised 2 datasets for each power plant, (i) the temperature of the cooling water intake and (ii) the temperature of the cooling water discharge having passed through the condensers. In each case data was available from January 2006 to June 2016.

The data includes 2 temperature readings taken daily in the intake and in the discharge, one at 02:00 and another at 14:00. In analysing the data, all the available measurements for the intake were considered, whereas only discharge data where the temperature interval between the intake and the discharge was ≥ 3°C was used in the analysis. The data for the intake is being taken for the purpose of this review as being identical to the ambient temperature in the Shannon at the two study sites, whereas the discharge temperature represents the maximum temperature that could be measured in the thermal plume at any given time, i.e. before any mixing with the receiving water and hence before any attenuation. The data was used to draw up the monthly trends in temperature for the 2 sites using a range of standard summary statistics (i.e. average, median, maximum, minimum, 5%ile and 10%ile) for each. These data were compared with the published thermal sensitivities of the fish species of interest, including variations associated with different life stages in order to gauge potential risk to the species in question. It is important to emphasise that the discharge temperature represents the highest possible temperature in the receiving water to which a fish could be exposed, i.e. before any attenuation has taken place through mixing with the receiving waters. In this respect, the discharge temperature summary statistics represent a worst case scenario in terms of potential risk. This is seen as the upper starting temperature, which will be attenuated to a greater or lesser degree through the dynamic mixing of the discharge flow and the receiving water flow. To date this interaction has been assessed quite comprehensively using thermal plume surveys which have consisted of mapping the extent of the discharge plume temperature both in the horizontal and vertical plains for up to 2.5 km downstream of LRP and 1.75km downstream of WOP during a wide range of river flows and ambient temperatures. These studies, which will be discussed in detail later in this report, reveal a plume which retains some fundamental characteristics under high, average and moderate river flow regimes, which only alters significantly during condition of low or very low flow. The assessment of potential risk to fish from the discharge will take as its 'worst case' starting point the temperature in the cooling water discharge i.e. BEFORE any mixing of the discharge takes place. This pre-mixing (i.e. discharge) temperature will be assessed in combination with the likely degree of attenuation as revealed by the various plume surveys undertaken to-date, in order to gauge the most likely receiving water temperature actually experienced by any given fish depending on its location within the mixing zone of the plume at any particular time.

Fish Community

Data on the likely resident fish community in the Shannon river at the two sites was based on the findings of two intensive fish surveys undertaken in May 2010 by Inland Fisheries Ireland (IFI) at Lanesborough immediately upstream and downstream of LRP and at Clonmacnoise, 11.5km upstream of WOP, as part of their Water Framework Directive (WFD) fish monitoring programme (IFI, 2010). The list of species recorded at each site and their numbers and densities is presented in Table 1 below. Also included on the list, are salmon, brown trout and sea lamprey, which are also known to occur in the Shannon and about which comprehensive recent and recent historical details were obtained from the ESB 2015 Annual Report on Fisheries. Although the two study sites are situated within Special Areas of Conservation, LRP (Lanesborough) in the Lough Ree SAC (Site Code 000440) and WOP (Shannonbridge) in the Shannon Callows SAC (Site Code: 000216), neither site has fish as a conservation objective. As can be seen from the IFI surveys at LRP and Clonmacnoise, the dominant fish community in these sections of the Shannon are coarse fish (roach, perch, pike, gudgeon, rudd, bream), lamprey and eels. Eel and lamprey densities are likely to be underestimates, given that electrofishing in deep waters isn’t the most effective means of capture of these species but the data allows identification of the relevant fish species likely to be present . More details of the relative importance of these species and why they have been included in the list will be addressed as appropriate when the implications for thermal sensitivity is discussed for each.

Table 1 Resident fish community at LRP and WOP (1-6) as revealed from IFI WFD fish survey in 2010 (IFI, 2010a) and known migratory species and brown trout

		LRP (A)		**LRP (B)**		**Clonmacnoise**	
		Nos.	Density (m^2)	Nos.	Density (m^2)	Nos.	Density (m^2)
1	Roach (*Ruitilus rutilus*)	111	0.00243	282	0.0081	87	0.00234
2	Perch (*Perca fluviatilis*)	73	0.0016	66	0.0019	76	0.00204
3	Pike (*Esox lucius*)	26	0.00057	11	0.00032	16	0.00043
4	Lamprey (*Lampetra* sp.)	10	0.00022	7	0.0002	2	0.00003
5	Eel (*Anguilla anguilla*)	5	0.00011	3	0.00009	1	0.00005
6	Gudgeon (*Gobio gobio*)	5	0.00011	-	0.00006	-	
7	Brown trout (*Salmo trutta*)	-	-	-	-	-	-
8	Salmon (*Salmo salar*)	-	-	-	-	-	-
9	Sea lamprey (*Petromyzon marinus*)	-	-	-	-	-	-

LRP & WOP Station Temperature Record – January 2006-February 2016

The summary statistics for the monthly variation in the cooling water intake temperature, which is taken to represent the ambient i.e. upstream temperature in the Shannon at each site, and the cooling water discharge temperature, which is the highest temperature that could be experienced in the plume, i.e. before mixing, are presented for LRP and WOP in Tables 2a & b and 3a & b, and Figures 1a & b and 2a & b respectively.

The intake and discharge data for both sites shows almost identical seasonal trends as one might expect. Both sites show January minima and July maxima, with June, July and August being the warmest months. There are some differences between the sites in terms of absolute temperature with average temperatures in the period March-to July warmer at LRP by up to a degree in some months, whereas, the reverse is the case for the period from August to February, when the WOP intake average temperature is marginally higher. December is an exception, with LRP having just marginally a higher average. A similar trend is evident in the temperature of the cooling water discharge at both sites, with LRP having a higher average temperature, up to one degree, from March to September and WOP being higher from October to February, except in December when LRP is marginally higher. The reasons for these apparent differences is not known, although the presence of Lough Ree upstream of WOP may be influential.

Maximum intake temperatures were higher at LRP from January to August, with the greatest differences from February to July (up to 1.24°C). In the discharge the LRP maximum temperature was higher in all months than the WOP discharge except in November and January. The greatest difference was during March when there was 3.5 °C in the difference, but normally these were less than 2°C. As maximum values only refer to a single event, they can be misleading, so an examination of the 5%ile and 10%ile values give a more representative picture of warmer years. The 5%ile data for the intake temperature shows that the LRP values were higher, by up to 1.17°C, from January to August, while in the remaining months the WOP intake temperatures were higher by up to 0.57°C. The LRP 5%ile discharge temperature was higher in all months than the corresponding WOP temperature by a maximum of 1.62°C. The data for the 10%ile temperatures followed a similar trend to the 5%ile data.

While the differences in the intake, i.e. ambient temperatures, between both sites are independent of the operation for both stations, the differences in the discharge temperatures between the two sites are influenced by the particular operational schedule operating at both stations, which isn't always the same. Both stations may not be generating at the same time and when they are they may be generating at different load levels, which in turn would result in different discharge temperatures and thermal loads. It is also important to point out that the summary statistics only used temperatures for the discharge when power was being generated and only when the temperature difference between the intake and discharge was at least 3°C. There were extended periods at both plants when there was no power being generated or generation was at a very low level. This can be appreciated by comparing the number of data points used to generate the summary statistic for the intake and discharge data (see last column Table 2a & 2b). In this respect, the discharge data can be read as very conservative.

The implications of the various temperatures recorded will be addressed in the following section dealing with fish species and groups of species.

LRP

INTAKE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	4.74	4.71	8.32	0.17	7.27	6.91	1.46	2.74	682
Feb	5.20	5.10	9.45	2.30	7.55	7.03	2.94	3.41	621
Mar	7.15	7.21	12.74	3.36	9.65	9.23	4.06	4.74	682
Apr	10.88	10.82	15.92	3.74	14.43	13.83	7.26	8.38	657
May	14.00	13.75	20.29	10.15	17.78	16.87	11.32	11.65	679
Jun	17.57	17.24	21.98	12.20	20.91	20.37	14.82	15.41	657
Jul	18.42	17.85	24.98	15.27	22.82	21.70	16.12	16.35	616
Aug	17.25	17.26	20.08	14.67	19.20	18.69	15.56	15.74	619
Sep	15.24	15.12	17.83	11.57	17.38	17.01	13.02	13.55	599
Oct	11.85	11.80	16.09	7.01	14.71	14.09	9.43	9.82	620
Nov	8.05	7.97	12.77	2.70	10.88	10.40	5.50	6.10	599
Dec	5.11	5.31	9.36	0.08	8.18	7.64	1.06	1.66	620

Table 2a Summary statistics for the Lough Ree Power station cooling water INTAKE temperature from 2006 to 2016

DISCHARGE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	11.70	11.80	15.28	6.34	14.16	13.79	7.92	9.61	653
Feb	12.27	12.22	16.87	6.83	14.72	14.22	9.87	10.32	596
Mar	14.28	14.38	20.33	9.39	16.99	16.47	11.08	11.73	642
Apr	17.97	17.88	23.68	10.53	21.67	20.77	13.82	15.49	590
May	20.69	20.22	27.68	15.57	25.10	24.03	17.90	18.38	452
Jun	24.76	24.53	30.08	17.56	28.55	27.90	21.56	22.26	517
Jul	25.90	25.29	31.26	20.90	29.98	28.92	23.39	23.78	484
Aug	24.53	24.70	27.60	20.43	26.28	26.01	22.18	22.93	473
Sep	22.09	22.24	26.89	16.02	24.64	24.25	19.04	19.73	434
Oct	18.84	18.94	23.87	12.46	21.85	21.07	15.40	16.80	560
Nov	14.92	14.92	19.44	9.41	18.58	17.73	11.75	12.43	546
Dec	12.12	12.12	16.82	4.84	15.36	14.61	8.21	9.09	607

Table 2b Summary statistics for the Lough Ree Power station cooling water DISCHARGE temperature from 2006 to 2016

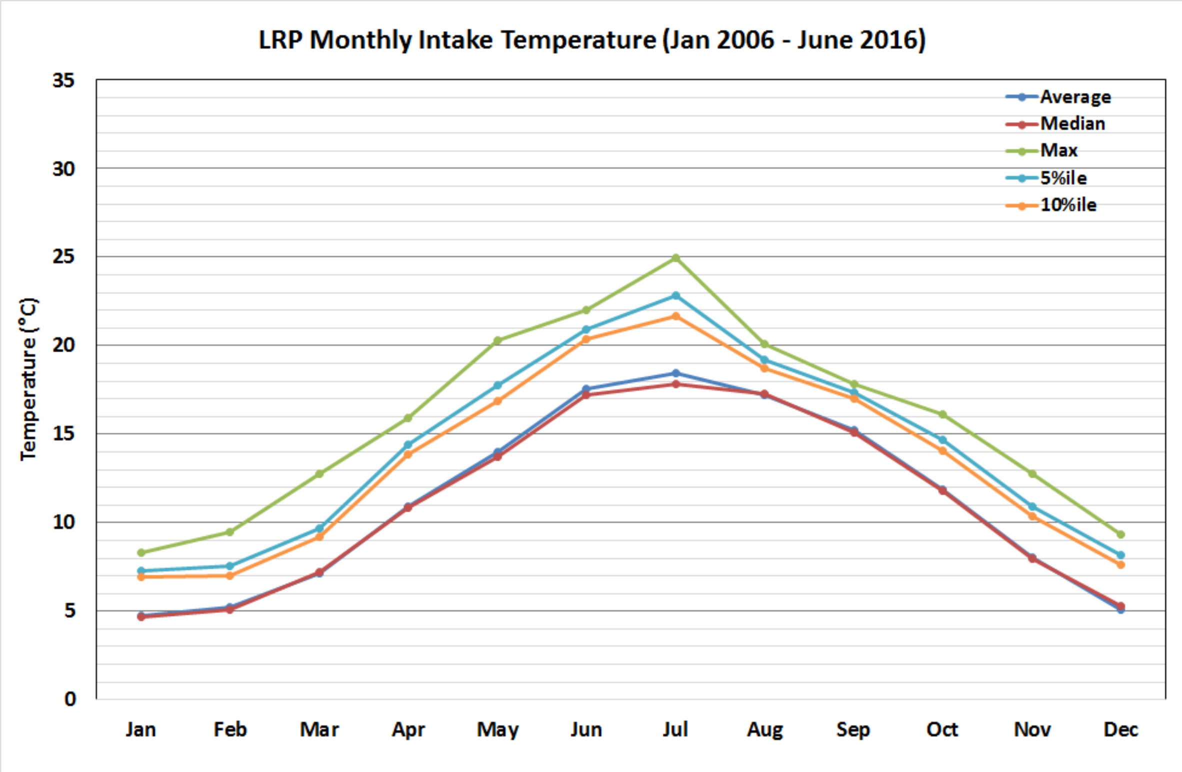

Figure 1a Graph of summarised monthly temperature variation at LRP cooling water INTAKE (2006-2016)

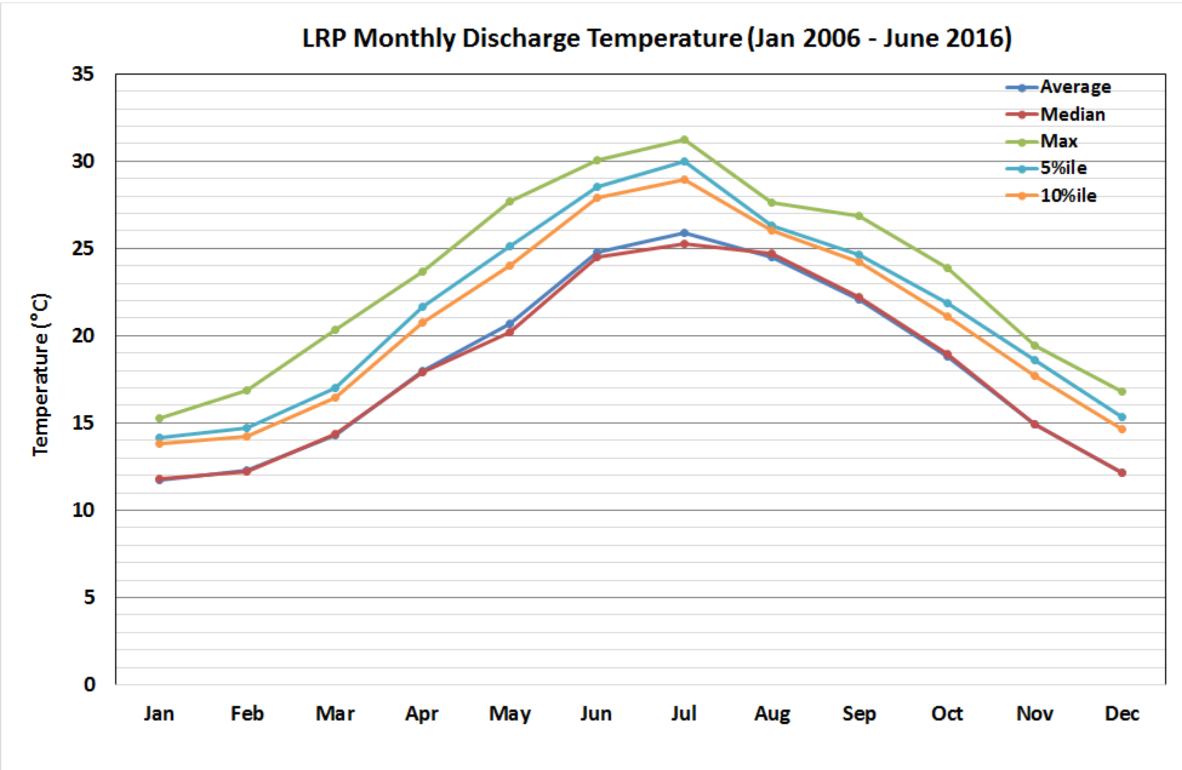

Figure 1b Graph of summarised monthly temperature variation at LRP cooling water DISCHARGE (2006-2016)

WOP

INTAKE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	5.00	5.11	8.30	0.74	7.18	6.93	1.84	2.94	676
Feb	5.31	5.30	8.77	2.65	7.50	6.85	3.25	3.56	622
Mar	7.02	7.23	11.55	3.86	9.10	8.65	4.42	5.04	682
Apr	10.32	10.30	14.89	4.12	13.25	12.61	7.17	8.15	653
May	13.53	13.37	19.05	9.98	16.74	15.92	11.21	11.49	681
Jun	17.02	16.81	21.33	12.18	20.30	19.76	14.12	14.85	657
Jul	18.19	17.74	24.10	14.17	22.30	21.19	15.95	12.29	620
Aug	17.34	17.31	19.90	15.34	18.83	18.45	15.94	16.20	620
Sep	15.58	15.47	17.95	12.59	17.53	17.28	13.76	14.04	601
Oct	12.54	12.67	16.40	7.40	14.93	14.23	10.39	10.83	617
Nov	8.77	8.76	12.89	3.65	11.46	11.03	6.10	7.00	601
Dec	5.68	5.87	9.37	0.34	8.39	7.80	2.40	2.82	620

Table 3a Summary statistics for the West Offaly Power station cooling water INTAKE temperature from 2006 to 2016

DISCHARGE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	11.27	11.66	15.74	5.65	14.13	13.76	6.86	8.16	620
Feb	11.85	11.97	15.72	7.48	14.36	13.90	9.12	9.48	601
Mar	13.45	14.12	16.82	7.74	15.93	15.47	9.89	10.39	569
Apr	16.92	16.99	21.88	9.28	20.06	19.45	13.13	14.92	411
May	20.31	20.32	25.80	14.20	23.82	23.15	16.69	17.42	524
Jun	23.64	23.46	28.56	18.66	27.65	26.77	20.25	21.14	427
Jul	25.22	24.74	30.06	20.13	28.94	28.24	22.48	22.79	450
Aug	24.12	24.14	27.36	19.23	25.75	25.49	22.13	22.88	371
Sep	22.06	21.95	25.31	16.95	24.48	24.07	18.93	20.34	400
Oct	19.08	19.14	23.47	13.10	21.58	21.07	16.03	17.21	544
Nov	15.34	15.35	19.46	8.96	18.42	17.75	12.45	13.24	591
Dec	12.09	12.45	16.29	4.71	15.17	14.63	7.51	8.85	614

Table 3b Summary statistics for the West Offaly Power station cooling water DISCHARGE temperature from 2006 to 2016

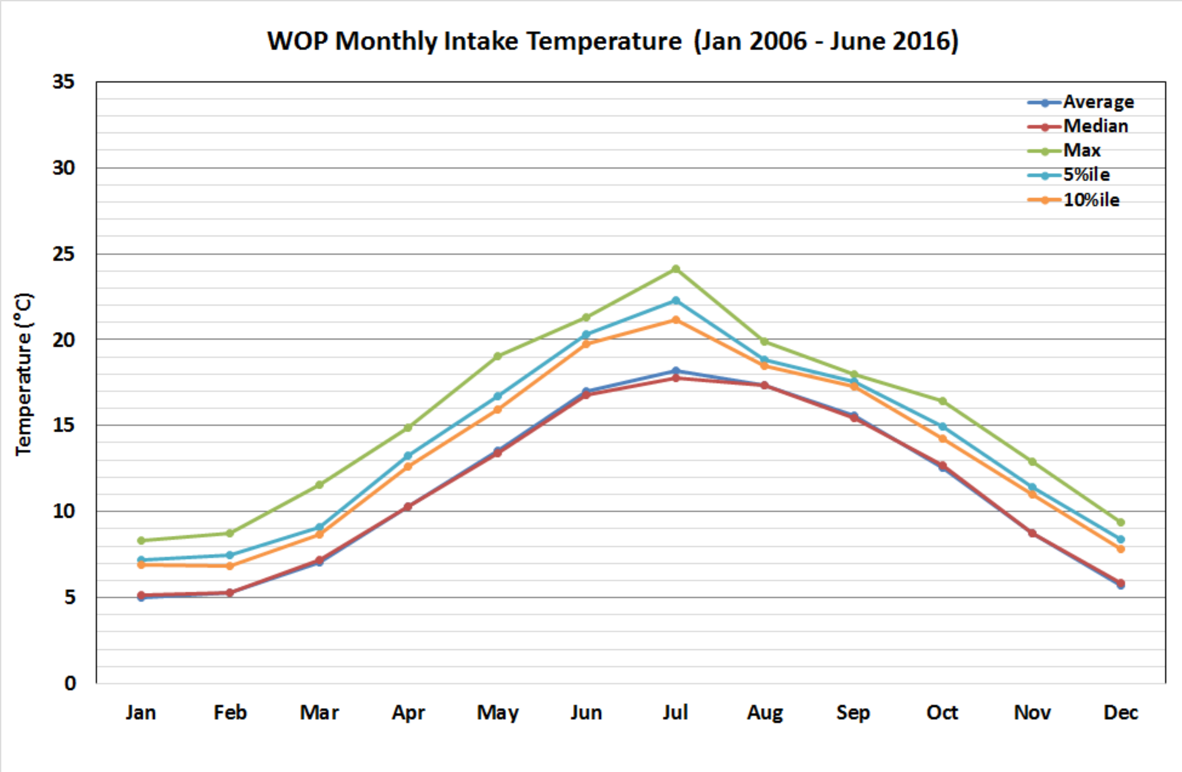

Figure 2a Graph of summarised monthly temperature variation at WOP cooling water INTAKE (2006-2016)

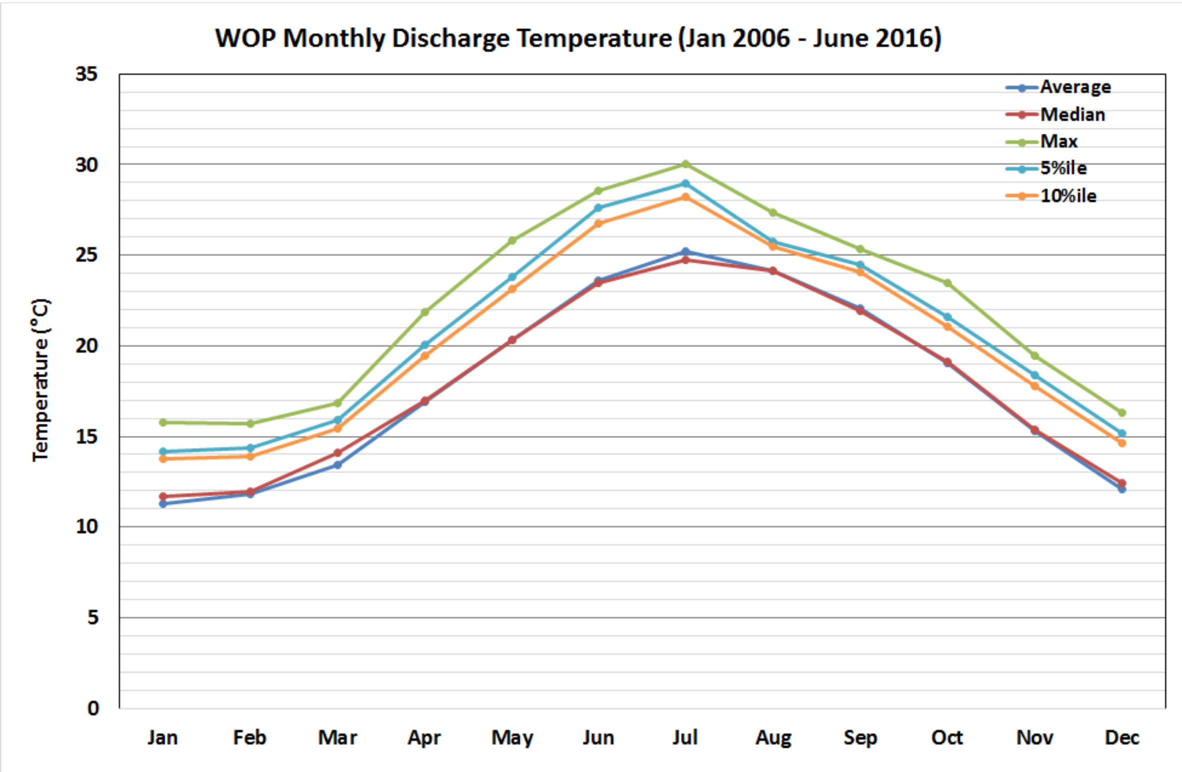

Figure 2b Graph of summarised monthly temperature variation at WOP cooling water DISCHARGE (2006-2016)

Assessing Temperature Preferences and Tolerances in Fish – Some Definitions

Methods for assessing the temperature preferences and tolerances in fish are discussed by Jobling (1981), who also reviews some of the terminology used and it is worth briefly discussing this as part of the review. According to Jobling the temperature responses of fish can be divided into tolerance, resistance and preference. Jobling illustrates the thermal responses of fish relative to acclimation temperature by the schematic in Figure 3. In order to define the zones of tolerance and resistance, plots of incipient lethal temperatures (tolerance limit) and temperatures at which death is rapid (resistance limit) are made against acclimation temperature. The upper and lower incipient lethal temperatures (IULT and LILT) represent the temperature at which theoretically, 50% of the population could survive indefinitely. Outside of the tolerance temperatures lies the zone of resistance within which there is a strong interaction between temperature and exposure time. The upper boundary of this zone is represented by the critical thermal maximum (CTM). Survival times above this temperature are virtually zero. The IULT, LILT and CTM are dependent upon acclimation temperature and the previous thermal history of the fish (Figure 3). The figure also shows that the boundaries of the tolerance zone are given by the IULT, LILT and the ultimate upper incipient lethal temperature (UIULT), which is the highest temperature to which the species can be acclimated. Within the tolerance zone delimited by these boundaries, a fish will tend to gravitate to preferential temperature zone within which the fish will make 'exploratory movements' into waters of higher and lower temperature.

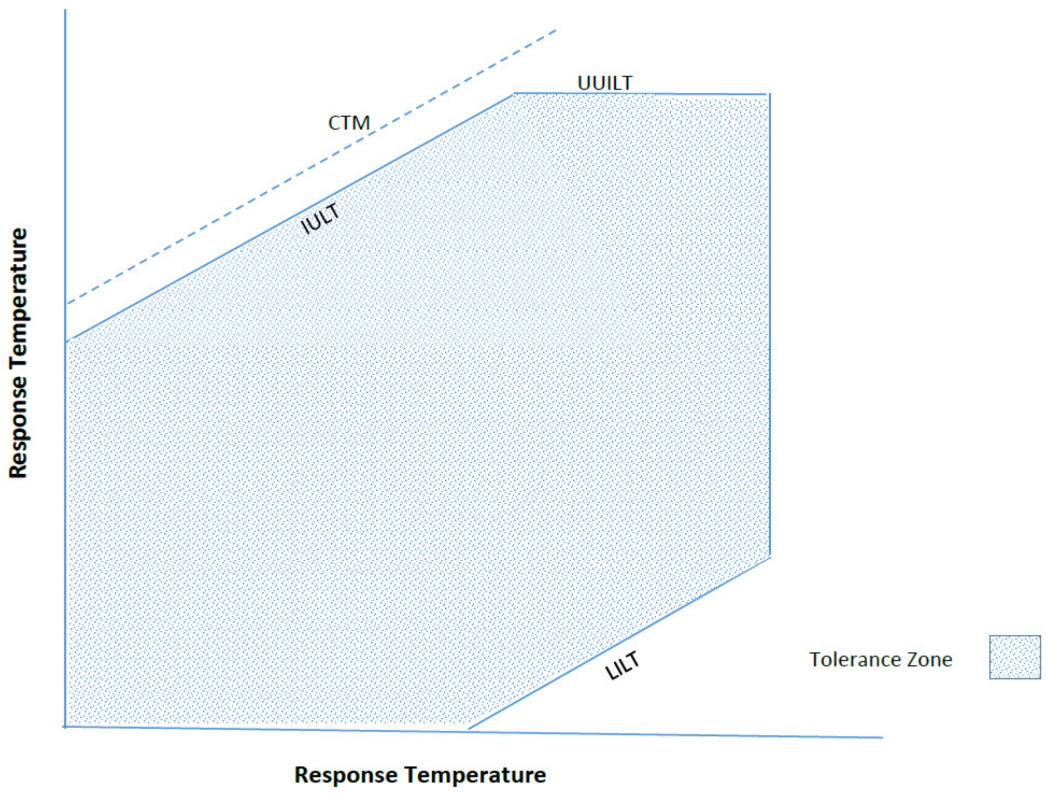

Figure 3 Schematic of theoretical fish thermal response limits (after Jobling 1981)

In the following section the published thermal optima/preferences and tolerance limits for the fish species of interest will be addressed. At this stage it is worthwhile briefly elaborating on acclimation temperature and its significance in determining what a given species can tolerate. In the context of determining what the IULT is for a species, the acclimation temperature is the temperature at which the test fish are held, usually for at least 1 week, before being exposed to fairly rapidly rising temperature increments until the IULT is reached, i.e. the temperature at which 50% of the test fish reach the nominated end point, which is usually some form of disorientation or loss of equilibrium, which will eventually be lethal. The exposure time set for the IULT test is generally about 1000 minutes i.e. a little over 16hours, although in some cases it may be longer. If removed from this temperature and placed in water of a lower temperature, fish would be expected to fully recover. The relevance of the acclimation temperature at which test fish are held is that as it rises the IULT also rises. However, there is a limit to which the IULT can be raised by raising the acclimation temperature and the resultant IULT for this highest acclimation temperature is referred to as the UIULT as referred to above. Therefore, in any given species, the IULT will naturally rise as the ambient temperature rises up to a maximum. In the context of the Shannon sites, this means in effect that as the temperature gradually rises in the river on a seasonal basis the tolerance of each species to higher temperatures also rises up to an absolute limit. This also means that in warmer years, the temperature tolerance of most species will also tend to rise. However, within these tolerance ranges (bounded on the upper side by the IULT), fish will naturally gravitate toward a preferred temperature zone (lower than the IULT) which itself will also tend to rise as the background temperature (i.e. acclimation temperature) rises. In the following analysis the IULT with acclimation temperatures, generally no higher than 22 to 25°C have been chosen as the upper limits of tolerance of the species under discussion. Higher IULT's e.g. derived for higher acclimations temperatures, where these have been reported, have not been used in the species risk assessments.

Thermal Optima and Thermal Tolerance of Fish

A large body of research into the thermal tolerances of a very wide variety of fish has been undertaken over the decades, especially in the 60's 70's and 80's but also more recently. This work has been undertaken in order to assess the impacts of thermal effluent from power stations, to determine the optimal temperatures for fish culture, and more recently in relation to the impacts of global warming. Much of these data have been conveniently gathered into reviews such as those of Alabaster and Lloyd 1980 (across the species range), Elliott and Elliott (2010) with salmon and trout, and Souchon and Tissot (2012) for a range coarse fish from Western European rivers. Data for eel, which wasn't available in these reviews was obtained from Sadler (1979) and Seymour (1989) and for lamprey ammocoetes from Potter and Beamish (1975). I have relied on these reviews to compile a table of thermal optima / tolerances for different life stages for each of the fish species of interest, using UK data, where available, in preference to continental European data or data from farther afield (Table 4). In the absence of specific data for brook lamprey (*Lampetra planeri*), data for the very closely related river lamprey (*Lampetra fluviatilis*) was used.

The reviews also give upper and lower temperature limits at which spawning takes place and these have been referred to where relevant, e.g. they are not quoted for eel, as they don't spawn in freshwaters. While there are no experimental data on IULT values for fish undertaken in Ireland of which I'm aware, wherever possible data on spawning temperatures (and dates) reported for a given species in Ireland are used in the analysis over data from other sources, although this is also quoted, and used in the absence of Irish data.

Thermal tolerance data for fish can be quite varied even within the same species, with much of the variation relating to either life stage and or the temperature at which the species were acclimated before testing. Generally, when faced with a choice, what appear to be high outliers were avoided and where an author pointed to a more typical value, the latter was chosen.

Species	Life Stage	Optimum	Cessation of Swimming	Upper Growth Limit	IULT	Acclimation Temperature	Observations on IULT
Brown Trout	Parr/adult	13.1-17.4		19.5	25		7-day limit
Atlantic salmon	Parr			22.5	28		7-day limit
	Smolts		20				
Eel	Adults	23-26.5		30-32.5	33-39	14-29	
Sea lamprey	Ammocoetes				29.5-31	5 & 25	
River lamprey	Ammocoetes				27-29	5 & 25	
Roach	Reproduction	10-18 (7-22)					
	Embryos	12-24			26		
	Juveniles	7-21		28	26.9-34.7 (30)		
		12-25			27.3, 29.4, 31.5	15, 20, 25	
	Adults				30.1-35.2	17-31	
Perch	Reproduction	8-15 (5-19)					
	Embryos	7-21 (12-18)			26		
	Larvae	12-25			36		
	Juveniles	10-25			31.4-33.5	25-30	32 considered most consistent upper boundary temperature
	Adults	16-27			24-31.4 (30-33.5)	6-25	
	Reproduction	8-15 (5-19) (Ireland, 9-14, early April to mid-May)					
Pike	Reproduction	8-15 (Ireland, 9.4-15.5)					
	Embryos	8-14 (4-23)					
	Larvae	12-21			28.4		
	Juveniles	19-21			29.4 (33)		29.4 = field; 33 = lab
	Adults	10-24		26-27	34 (31)		31 = most consistent
Bream	Reproduction	(Ireland, 15°C+, mid May-mid June)					
	Embryos	12-23 (upper boundary 28)			32		
	Juveniles	14-28					
	Adult	10-26			30.2	20	
Rudd	Reproduction	17.2-26.6 (Ireland 17-19 mainly, June-July mainly)					
	Adults			28	31.2	20	
Gudgeon	Reproduction	12-17 (24)					
	Embryos	16-20					
	Larvae	20.5					
	Juveniles	7-27					
	Adults				28.6		Possible underestimate

Table 4 Temperature tolerance limits in degrees Celsius for Shannon fish species and life stages (see text for further explanations)

Temporal and Spatial Characteristics of the Plume

The potential risk to the fish communities in the Shannon at LRP and WOP cannot be fully described without an understanding of the vertical and horizontal extent of the cooling water discharge thermal plume at both stations and how that can vary on a seasonal basis. The hydromorphology of the Shannon at both sites differs considerably and this has a bearing on the behaviour of the plume at each site. Recently, at the request of the EPA, several thermal plume surveys have been carried out by Irish Hydrodata (IHD) at both stations including one each in early spring (February 2015), late spring / early summer (April/May 2016) and late summer / early autumn (July/August 2014). The results of these surveys provide a good understanding of the extent and behaviour of the plume under a variety of flow conditions. Based on a combination of these reports, some general characteristics of the plumes at both sites are described below.

West Offaly Power (WOP)

February 5th 2015 (IHD, 2015a & b)

During this survey on February 5th the water level was at 37.4mOD, i.e. the 12%'ile level. This high water level resulted in the banks being over topped and as a result a large portion of the thermal plume discharging on the eastern side of the channel left the river channel within about 50m of the discharge point and flowed into the flood plain flowing parallel to the eastern side of the main river but outside it. The residual portion of the plume which continued along the eastern side of channel was confined to within 10-12m of the eastern bank and didn't extend to any deeper than 1.8m below the surface. The maximum temperatures for most of the plume was no higher than 1-3°C above ambient, which at the time was 3.1°C. The plant at the time was on full load with a cooling water flow of 5.4m^3/s and the incremental increase in temperature of the cooling water was 6.8°C giving a discharge temperature of 9.9°C, which is about 2°C below the 10-year (2006-2016) average discharge temperature at the station for the month of February (see Table 3b). At about 820m downstream of the station a residual portion of the flood plain bypass flow re-entered the eastern edge of the main channel and caused a small increase in ambient temperature for the following 50-100m downstream, before it completely dissipated. Again, the increment above ambient within the plume was no more than 3°C but mainly no more than 2°C.

April 28th & 29th 2016 (IHD, 2016a)

During this late April survey, the plume was confined to the channel as the river wasn't in flood. As in the February survey, the plume hugged the left bank and at most extended 25m into the channel, but closest to the outfall, where absolute temperatures in the plume were at their highest (max ~16°C at 0.3m below the surface) just 75m downstream of the discharge, the plume only extended 10m from the bank. At no stage did the plume extend more than 50% across the river and in terms of cross sectional area of the whole channel the plume never comprised more than 17%. Within the horizontal extent of the plume temperatures were highest toward the eastern bank, declining quite rapidly both in a horizontal direction toward the channel centre and vertically toward the deepest measuring point at 2m. At this latter depth the maximum temperature was generally no more than 2°C above ambient, occasionally spiking to about 2.7°C. But these rapidly dropped to 0°C above ambient (9.5°C) toward the outer edge of the plume and also declined longitudinally in a downstream direction. By 425m downstream the near surface temperature (at 0.3m depth) was no more than 2°C above ambient while at the same site the temperature at 2m depth ranged from 1.2°C close to the bank to 0°C toward the centre at the same depth.

The residual temperature rise in the river may have been about 0.4°C in the river, as this was the temperature measured above ambient at 1.9km downstream of the discharge, presumably after full mixing of the plume by that point.

At the time of the survey the station was on full load with a cooling water of 5.31m^3/s. The ambient i.e. upstream/intake temperature was approximately 9.5°C which is below average by at least 1°C for late April based on the 10-year record for the site provided by the station (2006-2016, Table 3a). The station discharge temperature 17.1°C was marginally above average for the station for the period 2006-2016. At the time of the survey the station was on full load and the incremental increase in temperature between the intake and discharge was measured at 7.3°C by the station. This is about 0.6°C above the April average for the station since 2006.

July 31st 2014 (IHD, 2014a & b)

The July 31st 2014 survey was undertaken when the station was on full load with a cooling water flow of 5.5m^3/s. The ambient temperature at the time was 19.5°C and the discharge temperature at the station was 27°C which is about 1.78 °C above the 10-year average for the discharge temperature but given that the sampling date is on the cusp of August, this may be closer to 2-2.5°C above average for this season. At the same time the flow in the Shannon at Athlone was about 91%'ile (pers comm Annmarie Downey, ESBI) which means that the survey is representative of more thermally challenging conditions in the river at this station.

Initially, although the plume remained close to the east bank, as in the February and April surveys, it then switched direction toward the west bank propelled by the momentum of the discharge flow. It subsequently appeared to move between banks until the first bend at around 650m downstream at which stage the plume mixed with the full flow producing a uniform 2-2.5 degree rise above the upstream ambient temperature which was still evident at 1700m downstream throughout most of the water column. While still intact, i.e. within the first 650m, the plume differed from those of the earlier surveys in that within this stretch it appears to have taken up a greater portion of the channel cross section at times. However, in as much as the highest temperatures were measured in the shallower depths, in this important respect it behaved the same as the April and February plumes. Based on the cross-sectional profiles taken during the survey, higher temperatures in the plume i.e. 4-<5°C were confined to the stretch within 300m of the discharge while the highest temperatures i.e. >5-<7°C were confined to the first 100m downstream of the discharge. In most cases also these more elevated temperatures were confined to the upper 1.5m, often the top 30cm. When the plume occupied the bulk of the channel, the majority of the temperatures in the cross-section were <2°C above ambient.

Lough Ree Power - LRP

February 4th 2015 (IHD, 2015c & d)

On the day of the survey the station was on 66% load with a cooling water discharge of 4m^3/s. The intake (ambient) temperature was just 2.4°C and the discharge temperature 9.8°C, an increase of 7.4°C. The latter was about 0.3°C above the 2006-2016 average for the intake-discharge increment for the month of February, while the actual discharge temperature was 1.9-2.5°C above for that time of year. The level in the river on the day isn't given in mOD, but seeing as on the following day the Shannon was flooding at WOP, it is reasonable to assume that the levels were also at the higher end of the scale at Lanesborough.

The plume was confined to the discharge canal retained there by the force of the flow coming down the main river on the west side of the channel. Within the discharge canal the plume didn't descend below 1m and generally hugged the eastern side of the canal. The highest temperature recorded in the plume (at 0.3m) was <6°C above ambient 50m downstream from the discharge. By 400m downstream the highest temperature in the plume, still at the surface and still hugging the east bank, was no higher than 3-4°C above ambient. At 450m the plume entered the lagoon area between LRP and Lough Ree where the bulk of the plume was <2°C above ambient within the residual plume cross-section. By 550m from the discharge there was no evidence of the plume remaining.

May 1st & 3rd 2016 (IHD, 2016b)

The flow in the Shannon at Athlone on May 3rd was 53.26m^3/s i.e., about the 63%'ile. The station measured the intake temperature on May 3rd at 11.3°C and 17.2°C in the discharge, an increase of 5.9°C. This discharge temperature is about 2°C lower than the 10-year average for the LRP discharge. The intake temperature was about 1°C lower than the 10-year average for the intake. The reason for the lower than normal increment between the intake and the discharge was most likely the reduced load at the station (66%) with a cooling water discharge of 4m^3/s at the time.

The bulk of the plume remained in the discharge canal between the discharge point and the entrance into the lagoon area about 475m downstream. Close to the water surface (0.3m) the water temperatures for the length of the canal were between 5°C and 6°C above ambient and remained so between the surface and the bottom (1.5-2m) throughout the canal. At breaks in the central linear 'islands' the heated water in the discharge canal flowed out into main river channel to the west but didn't extend beyond its centre line. Furthermore, below 0.8m depth within the plume, the temperature dropped rapidly from about 4°C above ambient at 0.3m to less than 1.3°C above at 1m and less than 0.2°C above at 2m, just above the bottom.

As the plume flows out into the lagoon, the surface temperatures were highest at the surface between 4 and 4.8°C above ambient toward the eastern side of the plume at 0.3m depth but by 1m below this had dropped to between 3 and 3.8°C above ambient, while at 2m it was less than 1°C above ambient. By about 600m downstream of the discharge the surface of the plume was less than 1.5°C above ambient, while on the bottom it was about 0.6°C above ambient, indicating effective dissipation at that point.

August 1st 2014 (IHD, 2014c&d)

This survey was undertaken when the station was on about 66% load and the cooling water flow was 4m^3/s. The ambient, i.e. intake/upstream temperature at the time was 19.5°C and the discharge temperature at the station was 27°C which is about 2°C above the 10-year average for the discharge temperature for that part of the season (Table 2b). At the same time the flow in the Shannon at Athlone was about 91%'ile (pers comm Annmarie Downey, ESBI) which means that the survey is representative of more thermally challenging conditions in the river at this station. The main difference in the behaviour and extent of the plume on this occasion compared to the May and February surveys, is that the plume crossed the entire width of the river and extended more or less symmetrically from bank to bank through the full extent of the lagoon at the northern end of Lough Ree. There are no temperature records for the discharge canal on the day because the depth (0.7m) was too shallow to navigate. However, one can assume based on the findings of the May 2016 survey that the plume temperature was close to 7.5°C above ambient for the majority of its length and depth. The plume spread across into the main channel via the 3 main gaps in the central 'island' and continued to the western bank. The temperature of the plume in the main channel at 0.3m below the surface began to increase from about 1.5°C above background at a point 50m downstream of the discharge reaching a maximum of about 7-7.5°C above ambient by the bridge at 175m downstream and remained at or above 6-7.5°C above ambient until the plume began to spread across the entrance section of the lagoon. Thereafter the plume temperature slowly declined toward the entrance to the Ballyclare Cut where it was 2-2.5°C above ambient remaining so through the cut and reaching 1-<2°C above ambient about 100m into Lough Ree proper and 0-<1°C from surface to bottom some 400m into the lake.

In terms of temperatures deeper in the plume, the main channel to about 250m downstream of the discharge remains at or below about 4-5°C above ambient below 2m depth. At the entrance to the lagoon, the temperature at 2m rose to between 5 and <~7.4°C above ambient, presumably because at that point the full flow of the discharge canal has joined the flow from the main channel downstream of the central dividing 'island's; the higher temperatures in this range were toward the eastern side of the entrance, i.e. on the same side as the discharge canal. By about half way through the lagoon at about 850m downstream from the discharge the top 2m was more or less uniformly located within the temperature band 4-<5°C above ambient from bank to bank (i.e. as far as the reed beds on either side). The considerable depth below this 2m contour was not surveyed, so we cannot say with confidence what the temperature at greater depth might have been, although the assumption is that it would have been lower. At 1250m downstream of the discharge (1500m downstream of the intake), the lagoon has become shallow again and the temperature, was within the range 2 - <2°C from 0.3 to the 2m and probably fully mixed from surface to bottom at 2.5m. By the entrance to Lough Ree at about 2000m downstream of the intake, the water column from 0.3 to 2m was in the range 1-<2°C above ambient.

In summary,

In winter, spring and early summer, it is probable that the western side of the main channel contains water at temperatures at or close to the upstream background level for its entire length and that the same pertains toward the western side of the entrance to the lagoon. Later in the summer and early autumn, (July and August) there are times when the plume reaches the western bank of the main channels and covers the entire area of the lagoon penetrating into the first 100-200m into Lough Ree, albeit at temperatures of between 1 and 2°C above ambient in the latter area. In winter and early spring, the plume in the discharge canal can be described as a surface phenomenon mainly, with deeper water in the canal near to ambient. However from early summer on, the plume along most of the discharge canal penetrates to the bottom with little or no temperature attenuation.

The form and relative thermal character of the thermal plume at the two sites, both horizontally and vertically, appears to be principally determined by the thermal load at the plant flow in the river at any given time, while absolute temperatures at any given point will also be determined by the ambient temperature at that time combined with the generating load in the plants.

Risk Assessment of Thermal Regime for Resident and Migrant Fish

In the following section an assessment of the risk posed by the thermal regimes in the Shannon at both power stations is assessed for the main resident fish species and those migrating through on a seasonal basis. To assist in this, the summary statistics for the temperature records of the cooling water intake and corresponding discharge for the 10 year period 2006-2016 (Tables 2a & 2b and 3a&3b) will be compared with the published thermal tolerance/sensitivity of different life stages of the species of interest, as a first step in assessing the potential risk to each. The intake temperature in this case is taken to be representative of the ambient i.e. upstream temperature for each station, while the discharge temperature is taken as the highest possible temperature in the thermal plume i.e. before full mixing and attenuation, thereby representing the worst case scenario. In further discussing the risk, the known behaviour of each species or life stage will also be considered and, importantly, the behaviour of the plume under various flow conditions, as revealed by the various seasonal thermal surveys undertaken to date by IHD, will also be taken into account.

Brown Trout (*Salmon trutta*)

Neither of the IFI WFD river surveys (IFI, 2009 and 2010a) encountered brown trout or salmon in the Lanesborough stretch of the river, or at Clonmacnoise on the Shannon 11.5km kilometres upstream of WOP. It isn't surprising that salmon are absent, as they would only be present as smolts migrating seaward in spring and early summer or as adults migrating upstream in summer, autumn and early winter. Brown trout however do form a continuing small proportion of the Lough Ree fish population, so one might expect that they would be present on occasion at least at Lanesborough. However, the dominance of coarse fish and pike in all surveys of Lough Ree (IFI, 2010b, Kelly et al, 2014 and Delanty et al., 2016) as well as in the Shannon (2009, 2011) at or near the power stations would suggest that the Shannon at LRP and WOP could reasonably be classified as being cyprinid waters.

This seems to be borne out by the published data on the temperature preferences and tolerances of the species when compared to the ambient temperature record for both sites (Figures 4a & 5a) which indicate that during the warmer months of June, July and August, that optimum temperatures for the species growth are only achieved under average temperatures and in warmer years (i.e. with above average temperatures), the growth rate is likely to be suboptimal or even halted, and this is before the influence of thermal discharges. These data do not indicate that trout are absent but rather that during high summer in warmer years conditions for the species appear to be sub-optimal at both study sites. When the same data is considered in the thermal plume (Figures 4b & 5b) it is very obvious that conditions at both stations could be sub-optimal from as early as April and as late as October depending on whether the year is warmer or cooler. This is more pronounced at LRP where the Upper Incipient Lethal Temperature (IULT) for the species (25°C) coincides more or less with average plume temperatures in June, July and August derived from historical (10-year temperature record provided by the station). At WOP, this is only the case in August. These data suggest that the species is likely to be entirely absent from the discharge canal at LRP in the period June to August in most years and only sporadically present between May and October in warmer years. Because it is a deep and open system and trout cannot be 'trapped' in the Shannon like they can be in very warm years in natal streams where they can be confined to deep pools. Under such conditions trout are known to descend to the deeper cooler parts of pools as a survival mechanism (Elliott, 2000). It is possible, following the same logic that trout in the LRP lagoon would retire to deeper waters in that water body in warm years, assuming that temperatures at the bottom are coolest. To date, however, we cannot say that with certainty because the deepest measurements to date have only penetrated to 2m. Any trout present could also just drop a little farther downstream into the main lake. In WOP any trout present could drop back down to cooler conditions in any warmer year, as temperatures began to rise seasonally.

There are no references to date for the existence of a Lough Ree version of the 'croneen' a brown trout population that occurs in Lough Derg and which migrates into the Little Brosna and on to the Camcor River to spawn. The migration usually begins around July. A much awaited comprehensive genetic study of brown trout in the mid-Shannon system is due for publication in 2017 which is expected to elucidate the relative importance of various spawning rivers for the species in Lough Ree (among other lakes). Until that is published we can only speculate as to how the operation of LRP might be affecting some or all populations of the species that occurs in Lough Ree.

None of the IFI surveys indicates that the LRP or WOP sites is likely to have a significant brown trout population.

Historical ambient temperature data at both sites would suggest that trout experience sub-optimal temperature conditions during warmer summers in the months of June, July and August, quite apart from any influence from the two power stations.

Any brown trout present in both station reaches are likely to avoid much of the area of the discharge plume, in the period June to August in years of average temperature and possibly for the period May to September inclusive during warmer years.

It is extremely unlikely that the thermal plume poses any serious disruption to the annual spawning migration of brown trout or the Shannon 'croneen' trout.

Atlantic salmon (*Salmo salar*)

Salmon are not a resident species in either the LRP or WOP reaches of the Shannon and the potential significance of the thermal discharges is for the migratory smolt stage on its seaward journey and the inwardly migrating adult fish either grilse or multi sea-winter fish.

The following data on salmon in the Shannon was taken from the ESB's 2015 Annual Report on Fisheries provided by Dr Denis Doherty, ESB's Fisheries Scientist who wrote the report and from whom some additional clarifications were also obtained. Apart from figures of about 3,800 and 2,800 in 2007 and 2008 respectively, total adult salmon numbers ascending the Shannon in the past ten years have averaged around 1,500 per annum. In 2015 the total was 1,456. Of these about 40% ran in the months June, July and August while 58% ascended from September 1st to December 31st. According to the 2015 ESB Fisheries Annual Report, the majority of the wild salmon spawning is located in the lower Shannon (particularly Lough Derg). Taking account of these details would suggest that perhaps as few as half of the salmon that began their ascent of the river in the warmer months of June, July and August i.e. around 300 fish would travel on toward Shannonbridge at ~75km from Parteen Weir and fewer again on to Lanesborough a further ~75km upstream. Thus only a portion of the fish returning to the Shannon is exposed to the potential risks of elevated temperatures from the thermal discharges in any given year. It may only take these fish a few days to reach Shannonbridge and Lanesborough if they move rapidly through the system, equally, however, it might take weeks. Their progress is likely to depend on a number of factors including: the number of physical barriers encountered, (perhaps the most significant being Athlone weir), ambient temperature, river flow and frequency of increases in river flow, physiological condition of the fish and proximity to the spawning season, among others. In short, it would be difficult to predict the average transit time of upstream migrants from Parteen Weir to the power station reaches. Furthermore, as the controlling factors will naturally vary from year to year the average transit time will also likely vary, at least somewhat. This would mean that fish entering in mid to late August for example might not arrive until well into September when on average temperatures would be cooler.

Salmon are significantly more tolerant of higher water temperatures than are trout and the highest ambient temperatures recorded at the two stations (24-25°C, Figures 4a & 5a) are 4 to 5°C lower than the IULT for the species (28°C), while the highest monthly average in July at both stations is about 10°C lower than the IULT. However, within the plume, during the months of June and July, in warmer years, the IULT is reached or exceeded (Figures 4b & 5b). In these situations adult salmon, especially during periods of reduced flow, could drop back down the river to avoid thermal stress and wait there until water temperatures decreased sufficiently and or there was an increase in river discharge to take them upstream past the affected reach. The thermal plume surveys undertaken in July-August 2014 (IHD, 2014a-d) at the two stations would suggest that the conditions at LRP would be more challenging during warm years than at WOP because vertical temperature profiles at WOP indicated that there were more stretches with cooler bottom water that would allow salmon travelling at depth to avoid the warmer surface layers of the plume. However, in the warmest years both sites could give rise to delays during periods of low flow. It's important to point out that delays in upriver migration are not uncommon in the species and don't automatically imply any adverse outcomes for the fish affected.

The other life stage that might be affected by the thermal discharges at LRP and WOP are seaward migrating smolts. The ESB operate a 'smolt protocol' at the dam at Ardnacrusha between mid-March (i.e. once the river temperature rises to around 8°C to 10°) continuing to around mid-June. This is an operating procedure using a particular power generation turbine (Kaplan) which is designed to facilitate the movement of smolts down past the dam with minimal mortality rates rather than have them delayed just above it. According to Denis Doherty ESB Fisheries, the duration of the smolt run varies quite a bit from year to year. Depending on whether the year is cooler or warmer the run might begin later or earlier, be of short and fairly concentrated duration or extended in a stop-start fashion. The latter will also be influenced by river flow, which research has shown is probably the most important factor affecting the rate of seaward migration. It usually stops in any case once water temperatures reach 18°C.

Smolts are likely to have the same upper thermal tolerance limits as adult salmon. Under ambient conditions smolts are never exposed to these temperature levels at LRP and WOP but in exceptionally warm years, late running smolts i.e. in late May or early June could in theory be exposed to these level in the plume. Against that, in warmer years one would expect that the bulk if not all the smolts would have already migrated, so the likelihood of any significant number of fish being exposed to this level of temperature in the discharge plumes is considered relatively remote. A more significant impact of the discharges however could relate to the rate of passage of smolts in warmer years. Research has shown that the optimum swimming speed of smolts is achieved at 13°C and that above 17°C this rate is reduced by up to 80%, while at 20°C smolts stop swimming actively (Martin *et al.,* 2012). These temperatures are not encountered in March in the discharge plume at either station and tend to be the exception in April, but occur regularly in May and are the rule in June at both stations with the effect being a little more pronounced at LRP (Figures 4b & 5b). We know from the 2016 thermal plume surveys undertaken in May 2016 that the plume at both LRP and WOP is mainly confined to the discharge canal and the eastern side of the main channel at the former and the eastern side of the channel at the latter, with very little impact on the western side of the channel in both cases. This means in effect that smolts can travel down past both stations along a parallel western stream where the temperatures are more or less at ambient and where they would be unaffected by the thermal discharge. This conclusion however is based on the assumption that the flow in the main channel is sufficiently high to ensure that the thermal plume is forced over toward the eastern side of the channel at both sites. The May survey undertaken in 2016 was not undertaken during conditions of seasonally low flows. Under low flow conditions, like those which pertained during the July/August 2014 thermal plume surveys (IHD, 2014a-d), the plume at both sites would in certain places occupy the entire channel, at least in certain stretches. If these flow conditions coincided with high cooling water discharge temperatures, then the rate of downstream decent of smolts could slow considerably in the affected reaches and they would be more likely to drift rather than swim downstream. This would in theory at least expose them to a greater risk of predation by pike resident in the affected reaches or to avian predators. Although, overall this risk is believed to be a minor one, it could be better evaluated with additional information about the typical flow conditions in the river during the months of April, May and June and how these flow levels affect the vertical and horizontal extent of the thermal plume.

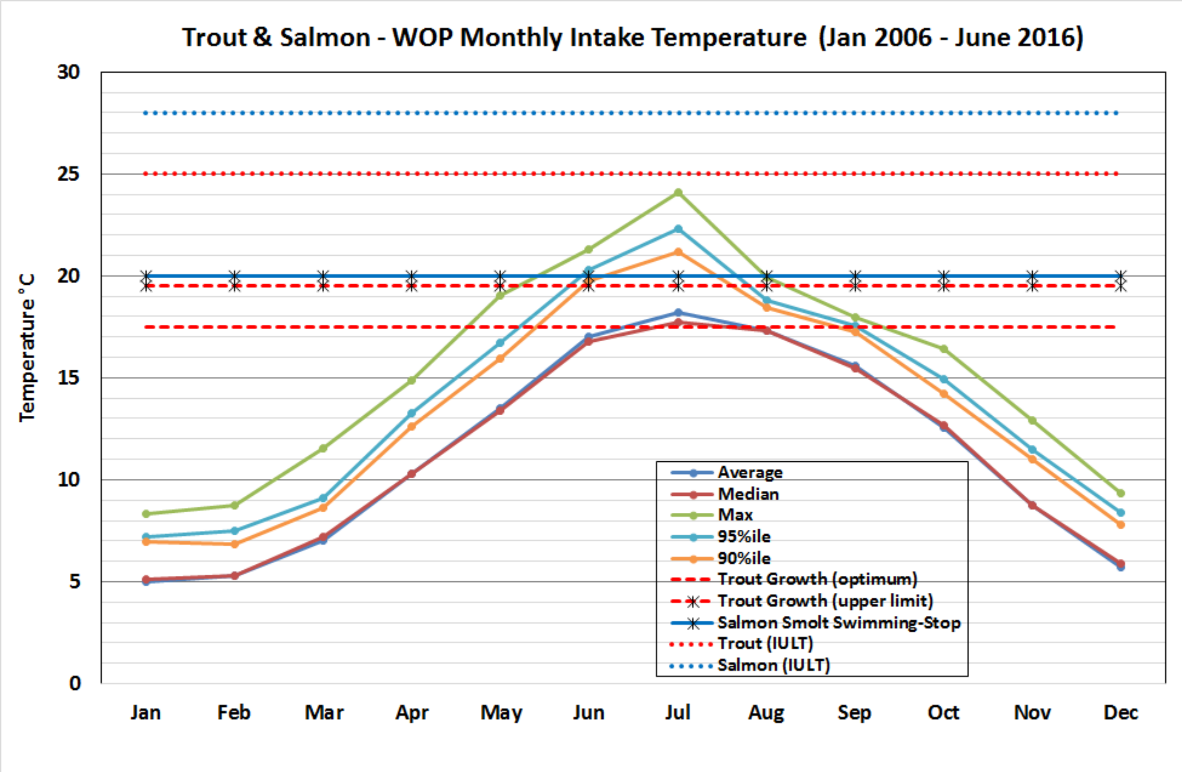

Figure 4a Trout and salmon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

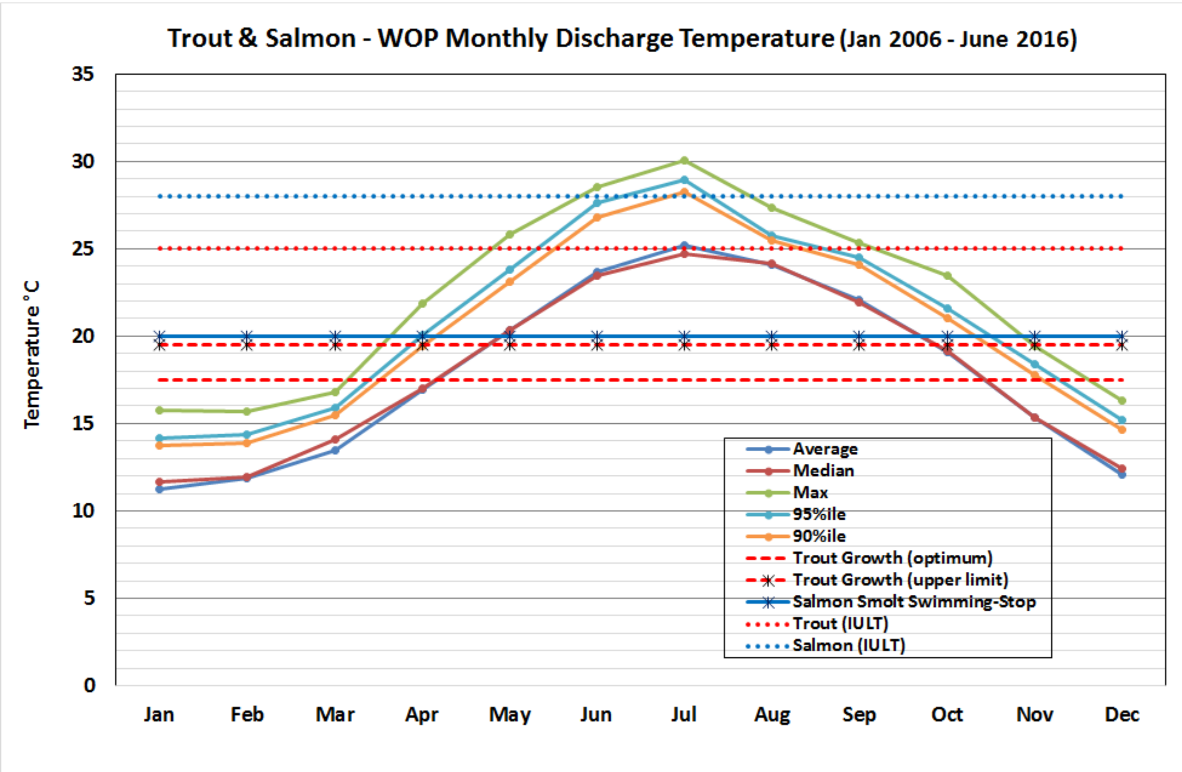

Figure 4b Trout and salmon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

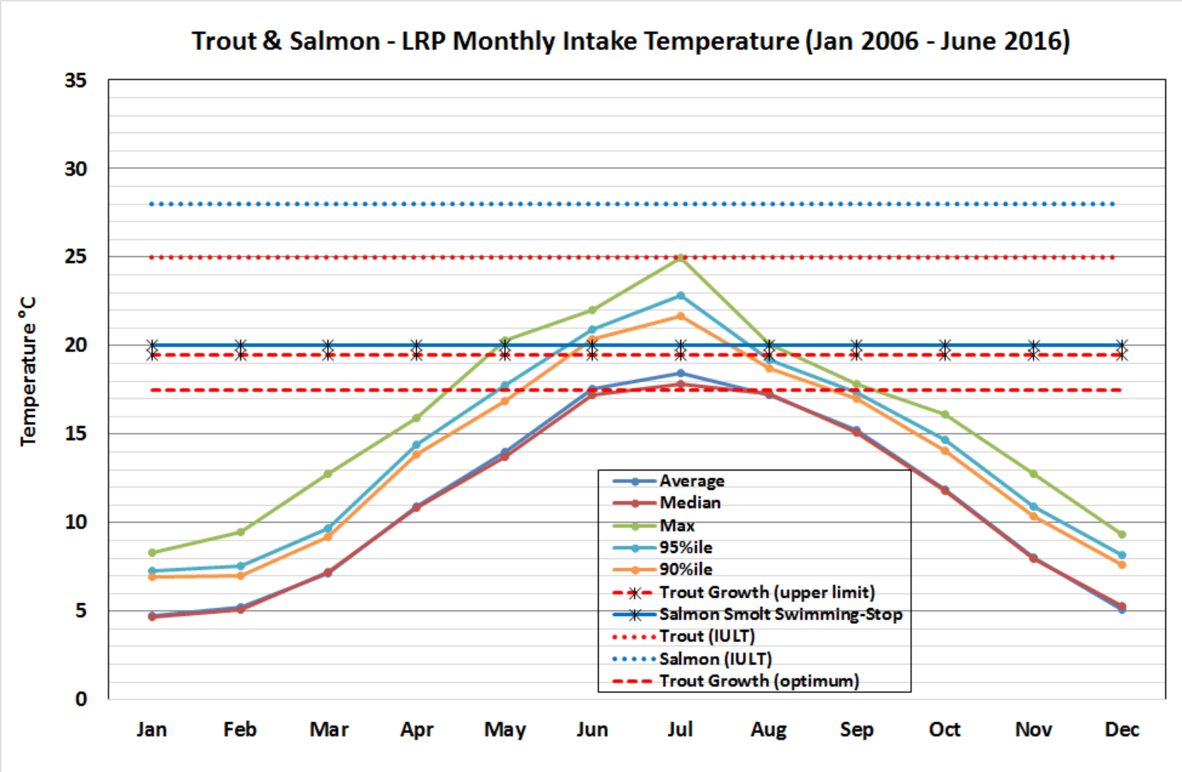

Figure 5a Trout and salmon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

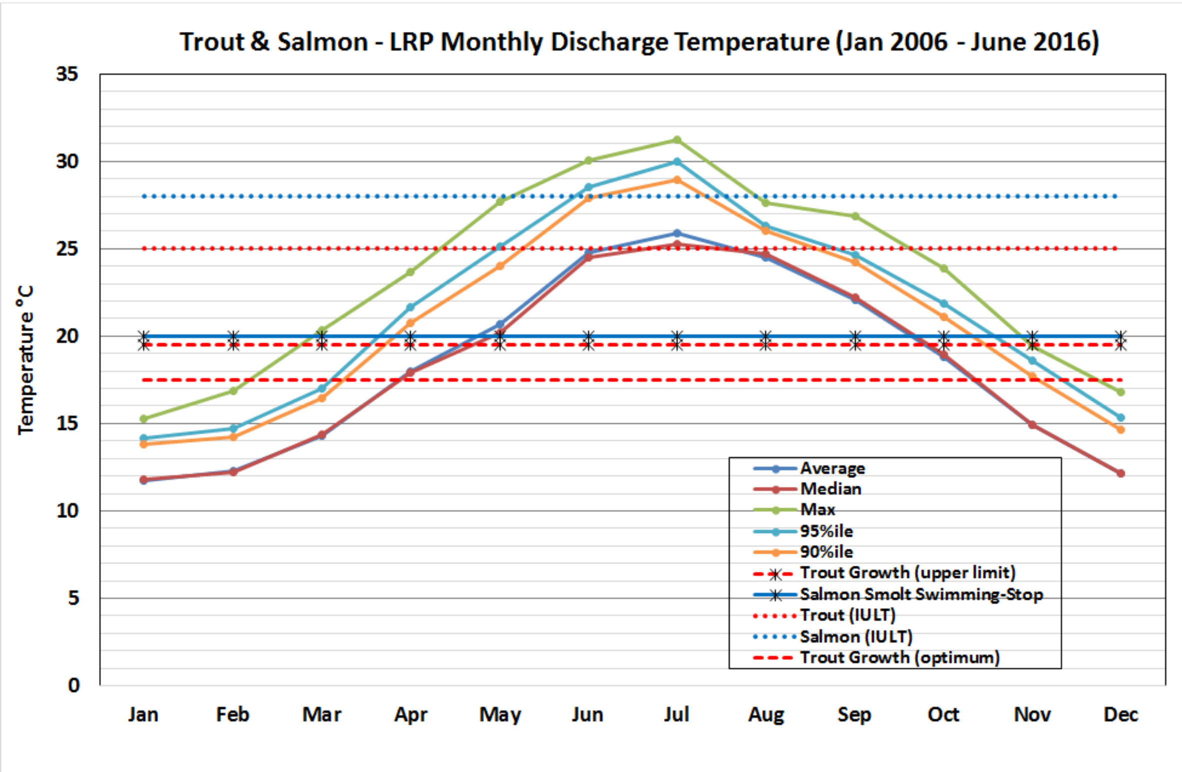

Figure 5b Trout and salmon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Eel (*Anguilla anguilla*)

The Shannon is one of the premier eel producing rivers in Ireland and the stocks are managed by the ESB. In accordance with the EU Regulation (2009), on eel the migration of silver eels ESB operates a trap & transport programme on the Shannon. The programme is monitored by IFI and the National Standing Scientific Committee on Eel issue an annual report to the Department. The T+T targets are set by NSSC Eel for ESB. A full report on the 2015 programme has been published and is available to download from the IFI website at http://www.fisheriesireland.ie/eels/939-ssce-report-2015-final-report-26-5-2016.

Due to the presence of the Parteen Weir and Ardnacrusha hydroelectric power station, downstream passage of migration-ready adults (silver eels) is facilitated by a system of trapping eels at 4 sites within the catchments above Parteen and their transport for release below the dam. Trap and transport as it's termed is carried out from August to February each year when most of the silver eels undertake their downstream migration. In 2015 no eels were trapped at the Killaloe weir (one of the trapping locations) during the months of August and September because of the low flows. The bulk of silver eels move at night during periods of high or increasing flow and during darkness. Adult eels have a high IULT (33°C) and a high optimum growth temperature 23-26.5°C. These data suggest that ambient conditions at both LRP and WOP are ideal for this species (Figures 6a & 7a). Furthermore, the 10-year historical record for the temperatures at both sites, when plotted against these temperature criteria indicate that even in the highest temperatures in the plume (Figures 6b & 7b) in the months when they migrate (August to February) silver eels are unlikely to encounter any difficulty in passing downstream through the LRP or WOP reaches; this assessment is further supported by the benthic habit of the species, which rest up and feed close to the bottom, where they would be exposed to lower temperatures under most circumstances.

Inwardly migrating juvenile eel (glass eel, elvers and fingerlings) are trapped at two locations in the Lower Shannon (Ardnacrusha and Parteen Regulating Weir), and are then transported upstream of the dam. In 2014 and 2015, 339.47kg and 418.9kg respectively of juvenile eel were trapped by ESB and transported for release above Ardnacrusha. These are trapped between March and September and released at into the Lower L. Derg catchment area and gradually disperse throughout the vast upstream drainage network of the river. According to ESB's records the recruitment of elvers to the Shannon, continues to decline, in common with rivers in the rest of Europe. At any one time a catchment may contain 10 to 20 age cohorts of eels, which mean that the bulk of the River Shannon's eel stock at any given time is resident rather than migratory. In this respect, the greatest potential effect of the thermal discharges would be expected to affect the resident rather than the migratory stocks of the species. The fact that this population is resident and has been a frequent component of the surveyed stock noted in IFI WFD surveys at LRP (IFI, 2009, 2010a) indicates that it has the opportunity to become acclimatised to the ambient temperature conditions at the sites, a factor which probably helps to reduce potential risks associated with elevated water temperatures. As indicated above, the summary record for the ambient temperature at both sites, when compared with the optimum growth requirements for the species indicates that thermal conditions are ideal for the species including during the warmest summers. Even below the discharges, i.e. within the thermal plume, only during the warmest years could conditions (in the warmest part of the plume) be considered sub-optimal (in terms of growth potential) but even then never approaching incipient lethal levels (33°C), (Figures 6b & 7b) However, as previously mentioned eels are further protected from exposure to higher temperatures by their benthic existence, which means that they are likely to be less restricted in their distribution even during the very hottest years during June and July. One cannot rule out the possibility that eels might avoid the warmest parts of the discharge canal at LRP during the very warmest years, especially in June and July, but this effect is unlikely to be significant when taken over the full period of the freshwater residence of any given eel and at a population levels it's effect would be negligible.

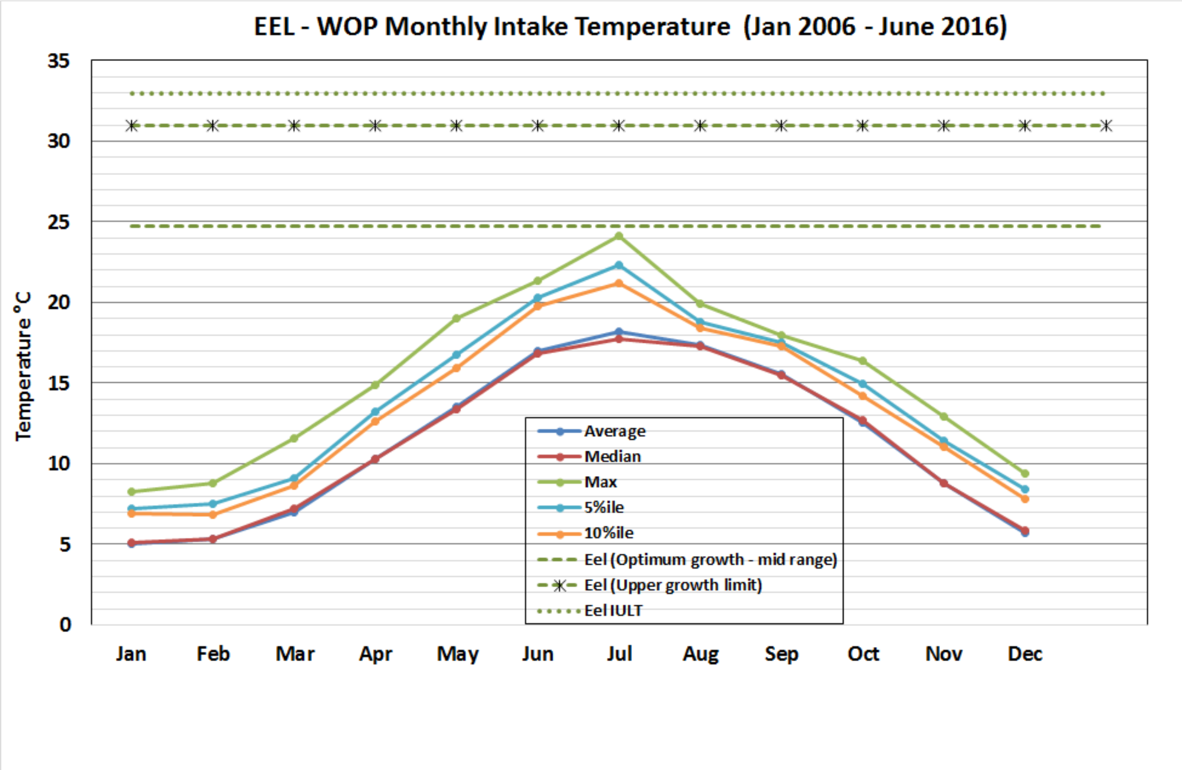

Figure 6a Eel thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

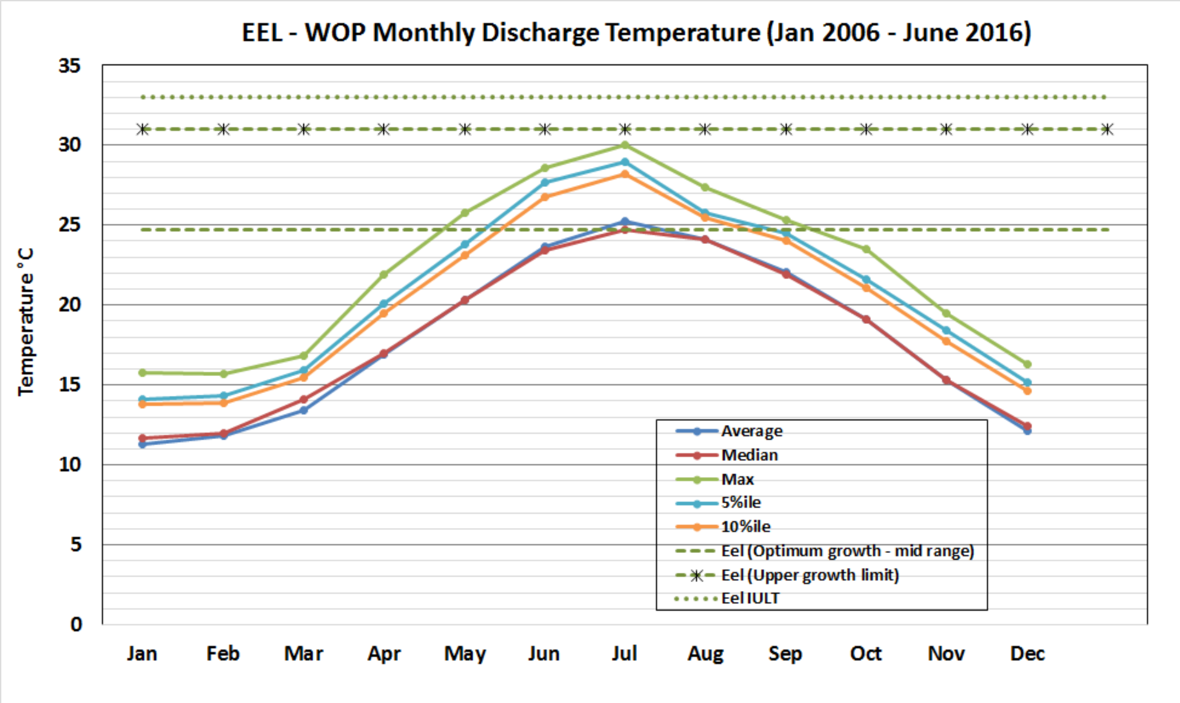

Figure 6b Eel thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

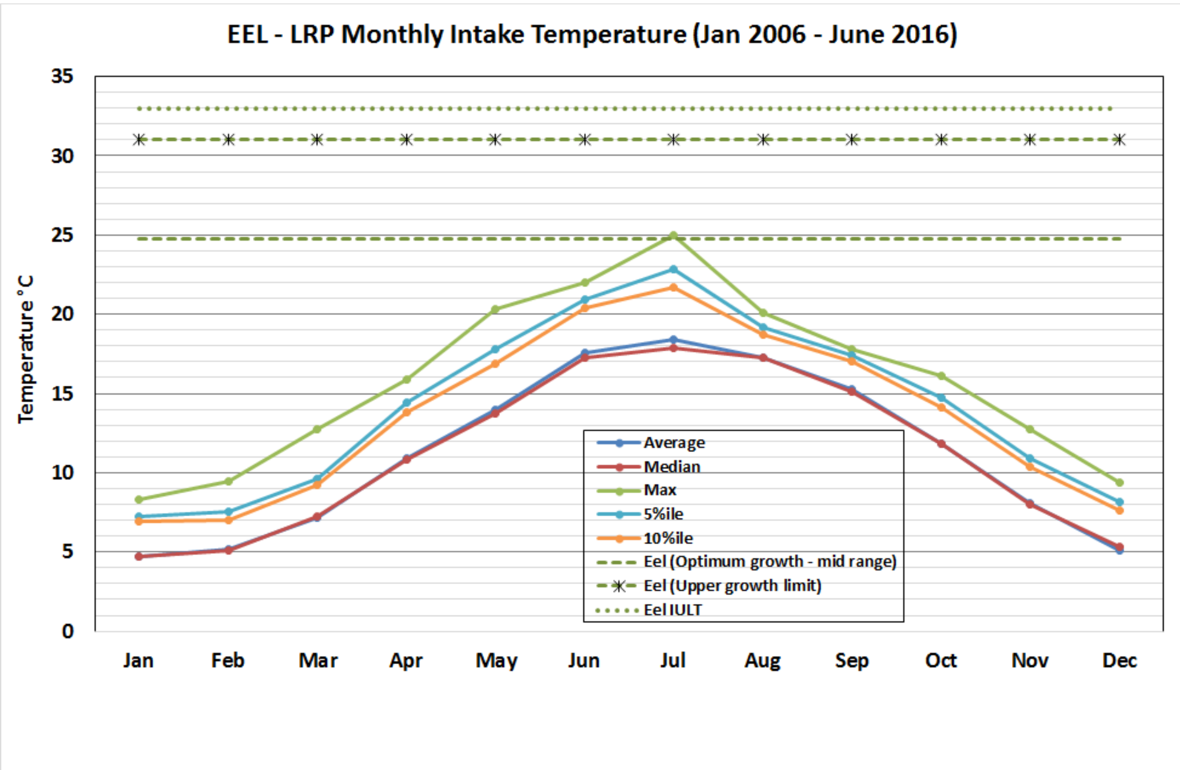

Figure 7a Eel thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

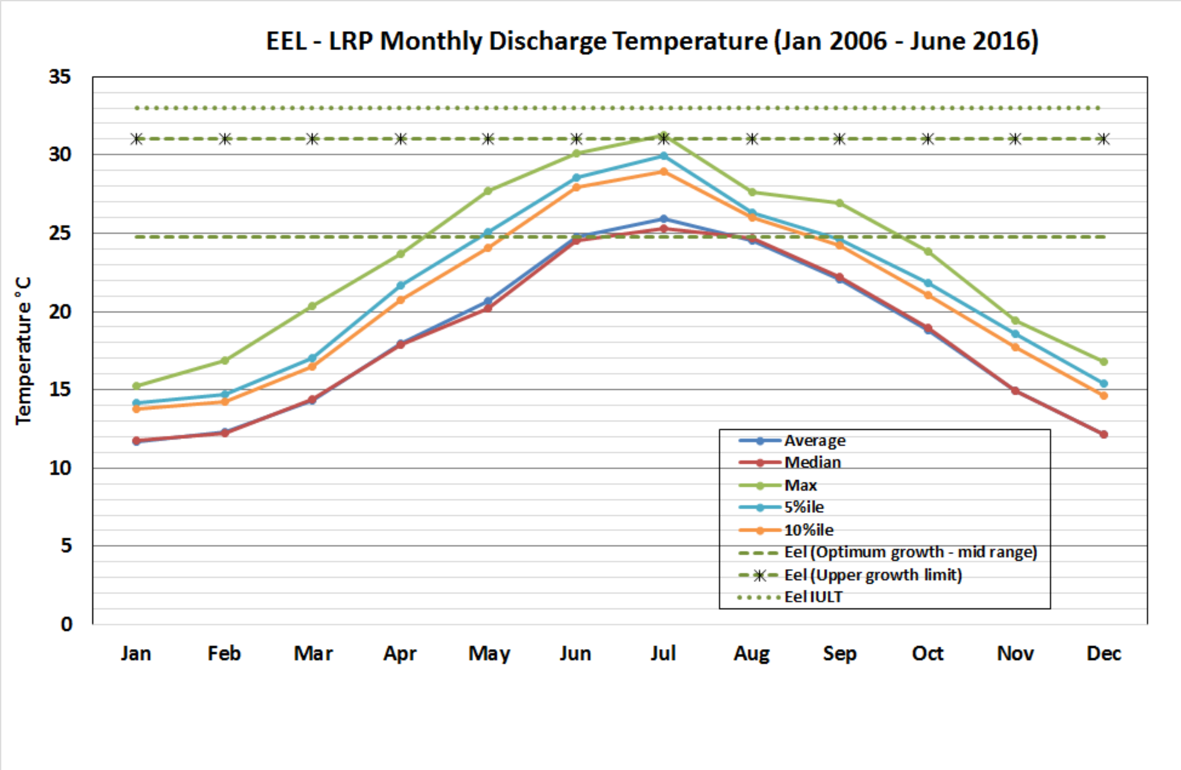

Figure 7b Eel thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Lampreys (*Lampetra* sp.)

According to the 2015 ESB Fisheries Annual Report – the anadromous sea and river lampreys appear to be confined mainly to the Lower River Shannon. This is partly supported by the fact that the IFI surveys at Clonmacnoise and Lanesborough have not encountered sea lamprey ammocoetes, all were belonging to the genus *Lampetra*. While these may also contain river lamprey, which is *Lampetra fluviatilis* and as ammocoetes are indistinguishable from their congener *L. planeri*, the brook lamprey, it is considered likely that if present river lamprey form a negligible portion of the population. The emphasis in this assessment is therefore on the non-migratory brook lamprey which are likely to be well represented at both sites. Neither stretch of river has conditions that would be suitable for lamprey spawning, so our concern here is with the ammocoetes which live buried in fine sediments on the river bed, where they grow for at least 3-4 years before transforming into small adults. Information on the thermal tolerance of the species was not encountered during the literature review however data for the lethal temperature for *L. fluviatilis* was encountered. Its IULT is measured at 29°C for ammocoetes acclimatised at 25°C. During ambient conditions at both LRP and WOP that temperature is never approached, even during the warmest months (Figures 8a & 9a). However, it is reached during the warmest years in July at WOP and June and July in LRP (Figures 8b & 9b) when the cooling water discharge temperature (before any mixing zone) is used as a baseline. Unlike other resident species lamprey ammocoetes lead a very sedentary existence and normally remain in their burrows. Clearly, if temperatures become intolerable they must either move or succumb. The likelihood is that they would move if temperatures began to approach IULT, even though examples of such movement resulting from elevated temperature were not found in the literature. If ammocoetes are displaced intermittently e.g. after high temperature episodes and perhaps replaced with newly arriving larvae during years where average or below average temperatures prevail, one might expect to find smaller i.e. younger ammocoetes in areas of suitable sediment in the discharge canal at LRP and along parts of the eastern bank for the first 300m downstream of WOP discharge which experience the highest temperatures, compared to the western side of both channels where lower temperatures would be the norm.

It may be noteworthy that temperatures in the cooling water discharge from LRP came within 0.5°C of the IULT (29°C) of the species and remained at or above 28°C for the period June 27th to July 2nd 2009, i.e. the year before the IFI carried out their last survey at Lanesborough (IFI, 2010a) where they recorded the same albeit very small density of *Lampetra* ammocoetes (0002/m^2) both upstream and downstream of the power station. It is also worth remembering that their bottom-living habit confers a degree of protection from exposure to highest plume temperatures. Overall, the temperature data suggest that there might be intermittent displacement of ammocoetes and or a possible reduction in their growth rates in areas of suitable habitat within the discharge canal at LRP and within the first 300m downstream of the WOP discharge, during very warm summers. However, bearing in mind the very wide distribution of the species (brook lamprey) throughout the Shannon system, that level of potential impact, were it to occur, is considered minor to negligible.

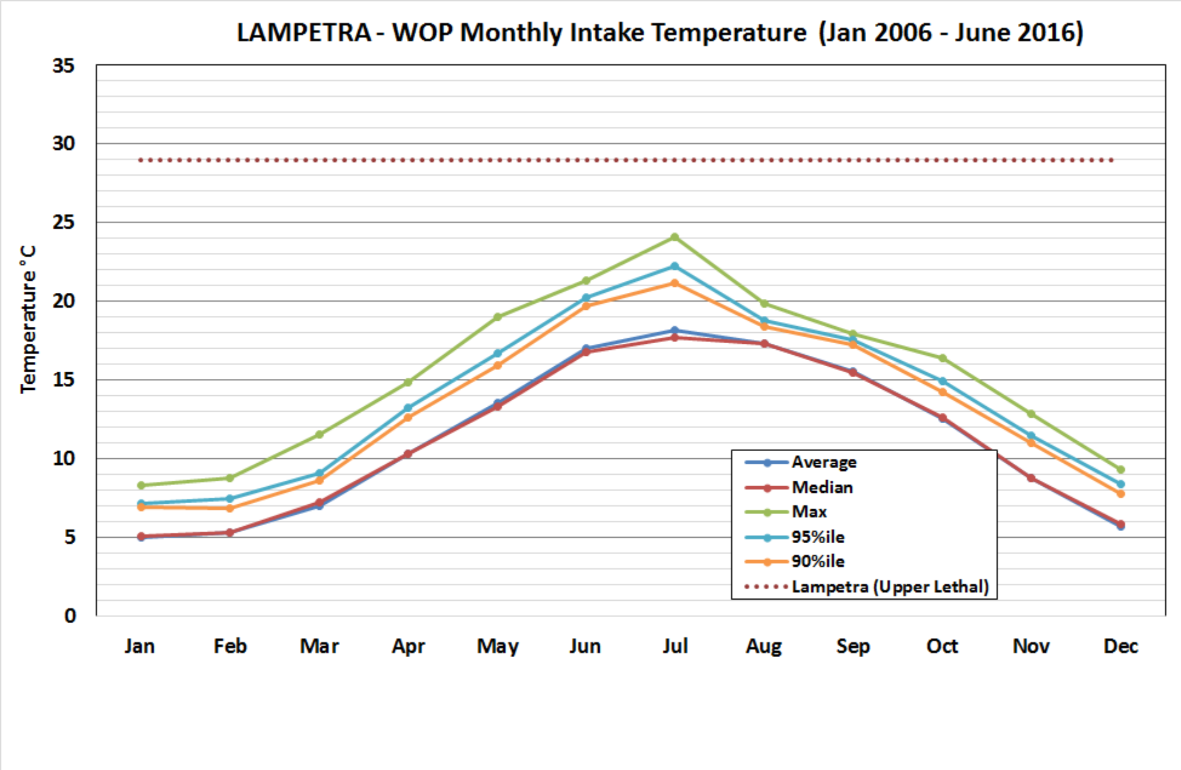

Figure 8a Lamprey (Lampetra) thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

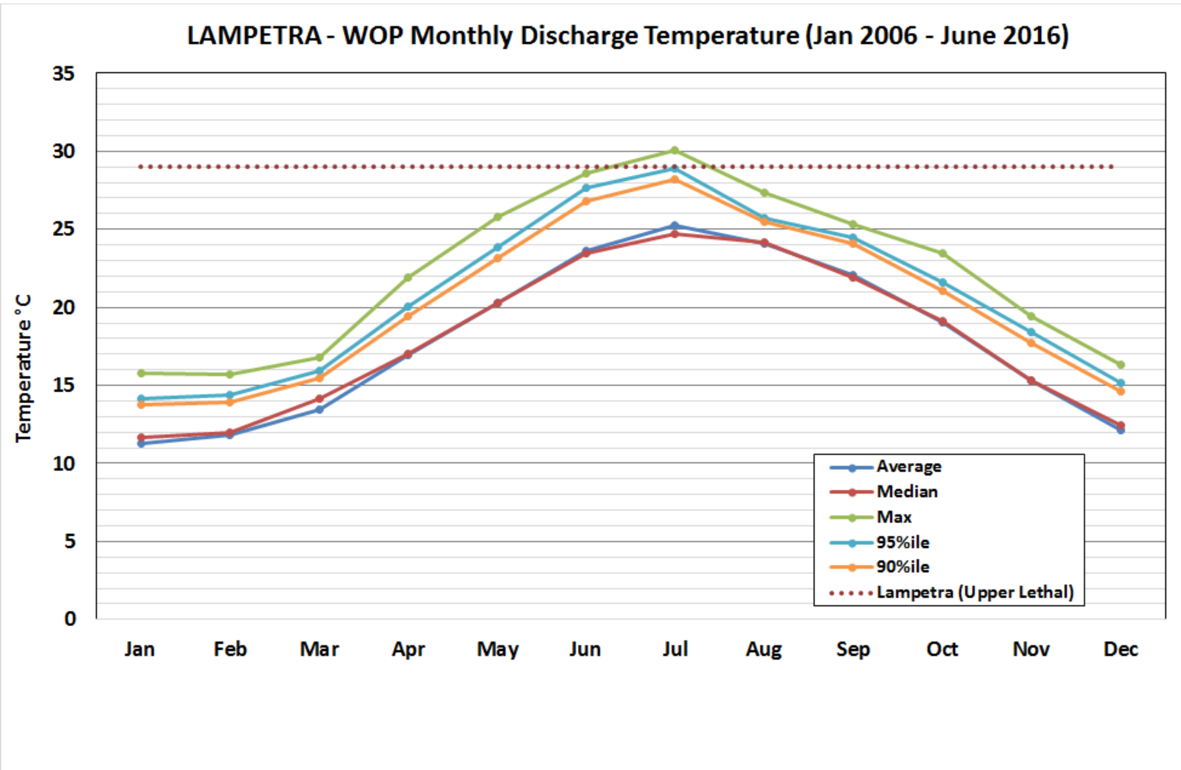

Figure 8b Lamprey (Lampetra) thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

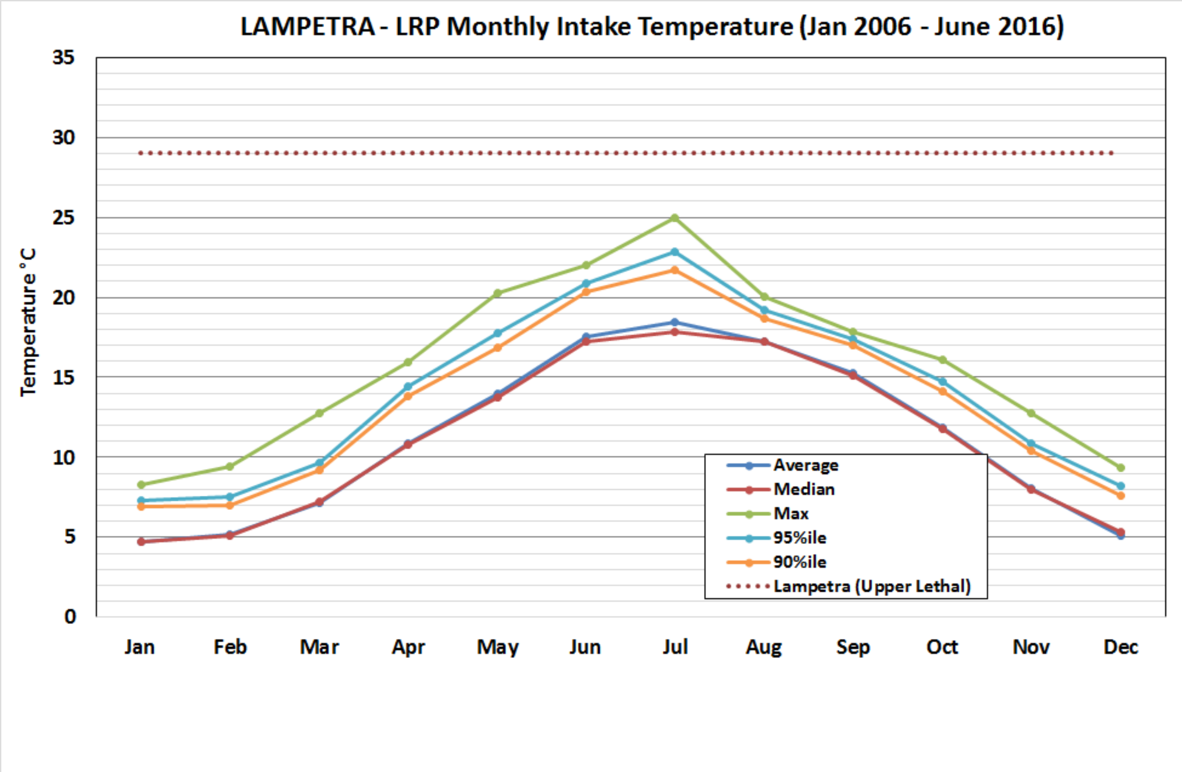

Figure 9a Lamprey (Lampetra) thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

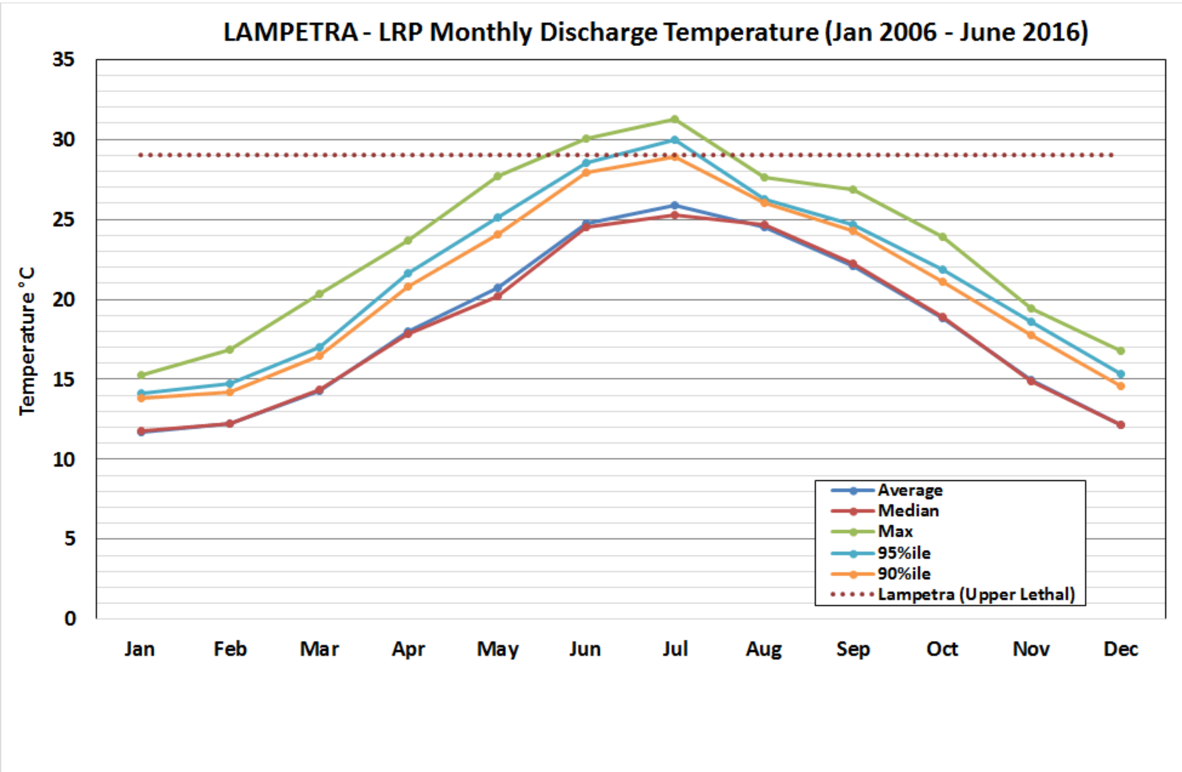

Figure 9b Lamprey (Lampetra) thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Pike (*Esox lucius*)

Pike formed an important component of the fish community both upstream and downstream of the power station at Lanseborough in the 2010 IFI WFD fish survey undertaken in May of that year (IFI, 2010a). It was equally prominent in the findings of the same survey effort at Clonmacnoise about 11.5km upstream of the WOP study site in very similar habitat. Based on data from a very intensive and detailed fisheries survey of Lough Ree in 2014, IFI state that Lough Ree pike are fast growing and long lived and that the population is large, balanced and uncropped (Delanty *et al.,* 2016).

Pike spawning in Irish lakes was observed by Kennedy (1969) to begin when the temperature reached 9 to 10 °C and was observed from Mid-February to late April depending on the year. After having commenced spawning they were observed to stop when the temperature dropped to 5.5°C but resumed again when the temperature rose to 12.7°C. At the LRP and WOP stations average ambient temperature in March is only marginally over 7°C and only reaches 10°C in March in warm years. The highest temperature at which Kennedy recorded spawning was 15.5°C and based on these data therefore it would seem more likely that pike in the LRP and WOP reaches of the Shannon, under conditions of ambient (Figures 10a & 11a), begin spawning sometime in early to mid-April in most years and finish by late May. Based on the summary 10-year data for the discharge at both sites (Figures 10b & 11b), pike could in theory be stimulated to spawn as early as January is some years because the average temperature in the plume at both sites is between 11 and 12°C in those months. For this to occur however, the spawning fish would have to have gonads developed to the correct stage to allow for spawning to occur, which is unlikely to be the case as early as January or even February. Furthermore, there would have to be suitable spawning habitat within the affected reaches as well. Kennedy (1969) observed spawning in the margins of Irish lakes usually in water shallower than 60cm over a bed of dead or living vegetation. However, pike in Lake Windermere are known to spawn also at depths from 2-3.5m. In LRP, the most likely place for pike to spawn would be in the lagoon area downstream from the discharge canal, which is flanked by beds of *Phragmites* and *Schoenoplectus*, but it cannot be said with certainty that pike would spawn here either. In their 2014 survey of 199 nettings sites through Lough Ree IFI found that pike were more or less evenly distributed throughout the lake except for significantly higher densities of fish in the bay just over half way down the lake into which the River Inny discharges, a concentration which the authors' suggest may be related to spawning migration. It is known from other lakes that pike seem to home to particular spawning areas each year. This offers the possibility that pike, particularly in the Lanesborough stretch, might migrate down into Lough Ree to spawn. However, the existence of favoured or large optimum spawning areas doesn't preclude the presence of smaller localised spawning areas spread throughout the system and on a precautionary basis we will make the assumption that at least some pike spawn in the marginal areas of both the LRP and WOP sites. Furthermore, given that the peak spawning time in Irish lakes has been observed to vary by as much as a month in consecutive years due to natural inter-annual temperature variations, it is considered possible that in some years, some pike may be stimulated to spawn earlier as a result of the presence of the plumes. This would be most likely to occur in years when low flows coincided with warmer temperatures, as it is only in such years, that the influence of the plume at LRP would be expected to reach the lagoon, the area where local pike spawning would most likely be expected to occur. However, this combination of factors is rare, i.e. the tendency is more for higher flows to coincide with cooler temperatures earlier in the year and indeed under conditions of low flow earlier in the year, the temperatures are more likely to be colder. In conclusion, it is considered less likely that pike in the main channel of the Shannon would be stimulated to spawn very much earlier than normal as a result of the thermal discharges due to the likelihood that flow conditions would be too high and the extent of the plume therefore too restricted. One possible exception would be if pike, as they have been noted to do elsewhere, spawn in the flood plain of the Shannon. During the February 2015 thermal plume survey at WOP, a substantial portion of the discharge was seen to exit the main channel to the east immediately downstream of the discharge during conditions of high flow and flow as a shallow stream in the flood plain running parallel to the main channel re-joining the latter some 800m downstream. If there were suitable vegetation in this 'bypass channel' there is a possibility that spawning-ready pike from the main channel might spawn there, given that the temperatures would be expected to be higher. Again however, we have no evidence to support this theory, although it cannot be ruled out entirely as a possibility during high flow years in February or March, when ambient temperatures would still be generally too low for spawning (in the river) but would likely be high enough based on the thermal plume survey findings (IHD, 2015a&b), in the 'bypass'. Overall, the possibility of some marginal advancement in the time of spawning of pike downstream of both LRP and WOP cannot be ruled out but if it does occur is only likely to affect a very small portion of the population in either reach and unlikely therefore to be associated with any measureable adverse impacts on the population.

The upper thermal tolerance levels reported for embryos in the literature (23°C) is such that by the time it is reached at both sites, young-of-the-year fish would be well beyond the embryo stage and therefore more thermally tolerant. Kennedy (1969) noted that at temperatures of 16-17°C embryos only took 8-10 days to develop into larvae.

As adults pike have fairly high upper thermal tolerance levels (IULT 30.2°C) and upper growth optima (26°C), they would be little impacted by the discharge in average temperature years (Figure 11b). However, in warmer years, pike may avoid the discharge canal during periods of low flow when the degree of temperature attenuation along the canal would be relatively minor (1-2°C) as seen in the August 2014 thermal plume assessment for the site (IHD, 2014c&d). It is worth noting that this ambush predator would still be likely to make excursions into warmer streams of the discharge plume if there were sufficient attraction in terms of prey availability. Overall, avoidance effects are unlikely to have a significant adverse impact on the local population other than a degree of local displacement during warm years combined with low flows i.e. mainly in June and July, an effect considered more likely at LRP than at WOP, because of the concentration of shallower flow in the discharge canal at the former site.

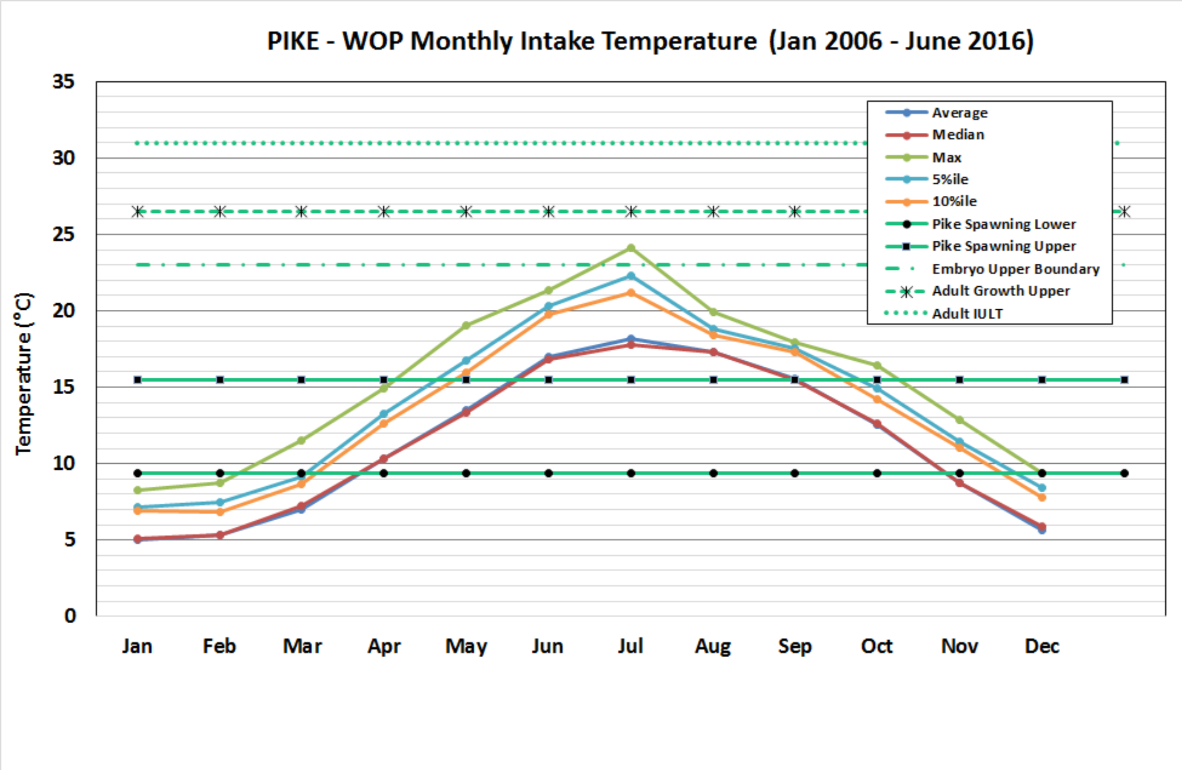

Figure 10a Pike thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

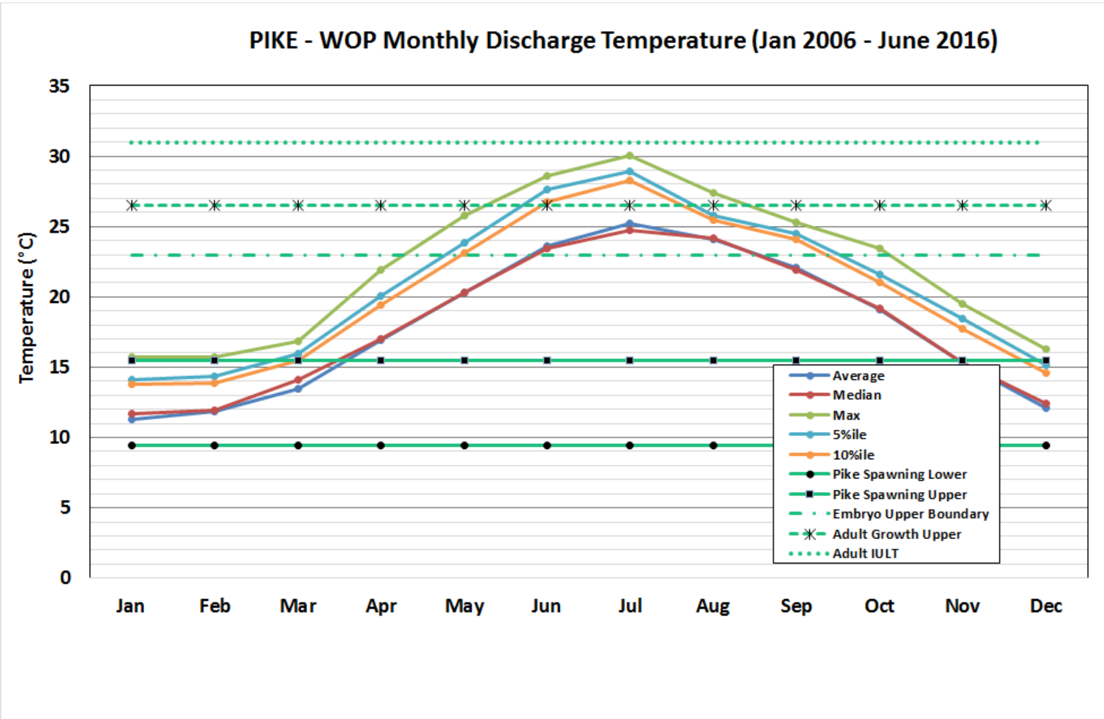

Figure 10b Pike thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

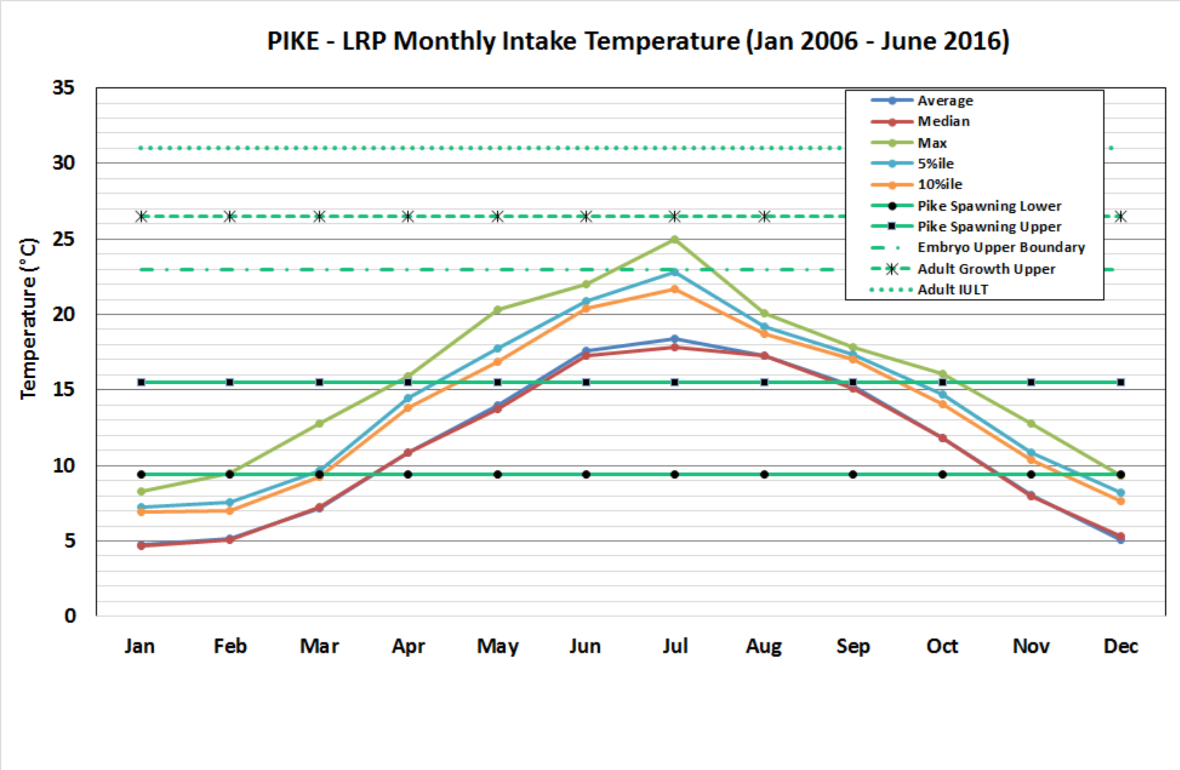

Figure11a Pike thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

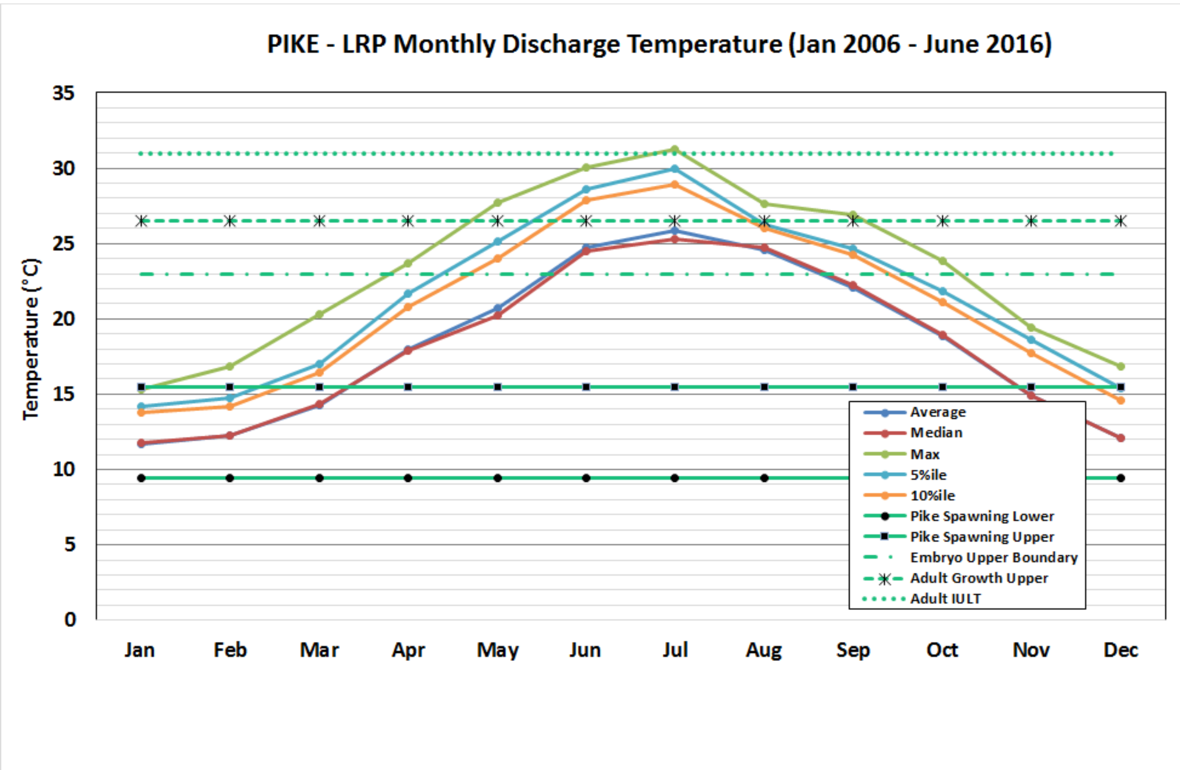

Figure 11b Pike thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Roach (*Rutilus rutilus*)

Roach, which are considered an invasive species, originally introduced to Ireland in the late 19th century, are believed to have entered the Shannon catchment at some time in the 1970's and are now a widespread and dominant component of the fish community there. The IFI WFD fish survey of 2010 at LRP and Clonmacnoise (IFI, 2010a) showed roach to be the dominant fish by a considerable margin at both locations including at sites upstream and downstream of the powers station at LRP. In a recent (2014) very intensive survey of Lough Ree covering 199 netting sites distributed throughout the lake (IFI, 2016), roach were present in more than 85% of sites and in total constituted about 52% of the total number of fish netted, making the species by far the dominant species. The Catch Per Unit Effort (CPUE) for the species at 21.4 is at the higher end of other surveyed lakes in the region but the report suggests that the population is likely to have declined in recent years due to the introduction of the zebra mussel which has had a very heavy cropping rate on phytoplankton. Roach are believed to thrive in culturally eutrophic waters and clearly the conditions in the Shannon must be ideal for the species.

No data on the timing or temperature for roach spawning in Ireland was obtained. In the literature spawning was noted in mid- May on the Meuse in Belgium and in Lake Geneva, while a late May spawning was noted in Manchester in England. In that latter study roach spawned at water temperatures of 12-14°C, temperatures also consistent with the Belgian and Swiss observations. At the Shannon sites, these temperatures are reached on average during May, probably from about the middle of the month on (Figures 12a & 13a). It seems reasonable therefore to assume that roach spawn in the study areas from mid-May to late May although an earlier commencement date cannot be ruled out, as Irish spawning temperatures are sometimes lower than in the UK and in Europe. Roach spawn in river backwaters and shallows where their eggs stick to vegetation and hatch in 9-12 days at 12-14°C (Wheeler, 1978).

It isn't known whether roach spawn within the study areas but some limited spawning may possibly occur in the breaks between the central 'islands' or along their margins in shallow vegetation and / or in the margins of the lagoon at LRP. There is also much marginal vegetation upstream and downstream at WOP but whether it is sufficiently protected from the flow to constitute suitable spawning habitat is not known. As a precautionary approach, it is assumed that at least limited spawning of the species is likely at both sites.

If we assume that roach spawn around mid-May under ambient temperature conditions at both sites, it is possible that downstream of the discharge they could do so in April, as the temperatures in the plume would already have reached those levels by late March in the discharge canal at LRP and also downstream of the discharge at WOP. However, fish would not spawn unless their gonads were already sufficiently developed. Roach spawning on the Meuse in Belgium did so 3 weeks earlier in water of 2-3°C higher than ambient downstream of a power plant discharge (Mattheeuws *et al.,* 1981), so the possibility of this occurring at the study sites would seem reasonable, so that an early to mid-April spawning might occur. In April one would expect the flows on average to be somewhere between what they were during the February 2015 thermal plume studies and the April/May 2016 thermal plume studies at both sites (IHD, 2015 a-d & 2016a&b). In each case temperatures greater than 2-3°C above ambient were confined to the eastern side of the channel and extended for 200m-300m downstream at WOP and between 300-600m downstream at LRP. In the context of the size and extent of the roach population within the Shannon at both sites, these impacts, should they occasionally arise could be described as negligible.

Embryos derived from earlier spawning in the warmer areas referenced above would develop at a quicker rate and would therefore be at a more advanced developmental stage earlier and therefore unlikely to be affected by thermal stress as given by the upper boundary figure of 24°C (Figures 12b & 13b).

Temperatures for adult roach downstream of the discharges would enter sub-optimal territory (>25°C) within the plume during warm years in June, July and August. However, the species is known to inhabit waters of 27.5°C in the River Trent in comparatively large numbers in June (Sadler, 1980) and is known to be attracted to the discharge canal at LRP where in the past at least it was a popular target species for coarse anglers. It seems reasonable to assume therefore that adult fish are unlikely to be adversely impacted by temperatures at least up to 27.5°C. Indeed one of the features of the roach fishery in the Lanseborough discharge canal was the fact that the season was so long, i.e. from April to October, when under natural conditions it would have opened later and closed earlier. During the very warmest years, July temperatures in the cooling water discharge approach the IULT for the species (31.1°C) at WOP and exceed it at LRP (Figures 12b & 13b). Under these conditions some avoidance of the discharge canal and the inner section of the lagoon i.e. within the first 600m downstream of the discharge point, might in theory at least occur. Due to the nature of the plume and its vertical distribution at WOP during periods of low flow as revealed in the July 31st 2014 thermal plume survey (IHD, 2014a & b), roach are unlikely to show any significant degree of avoidance of the discharge stretch although they may drop deeper and congregate in sections of the cross-section which are cooler. Should they occur, these impacts are likely to have very little significance for the roach population, even at a local scale.

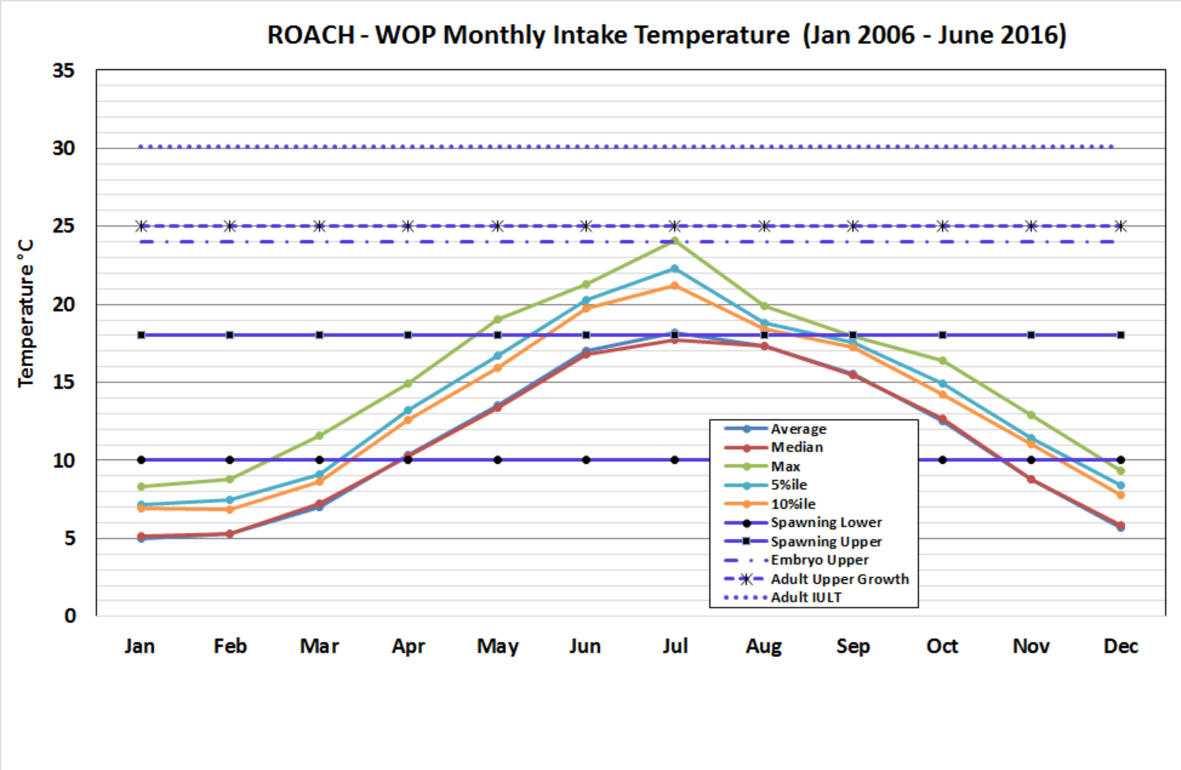

Figure 12a Roach thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

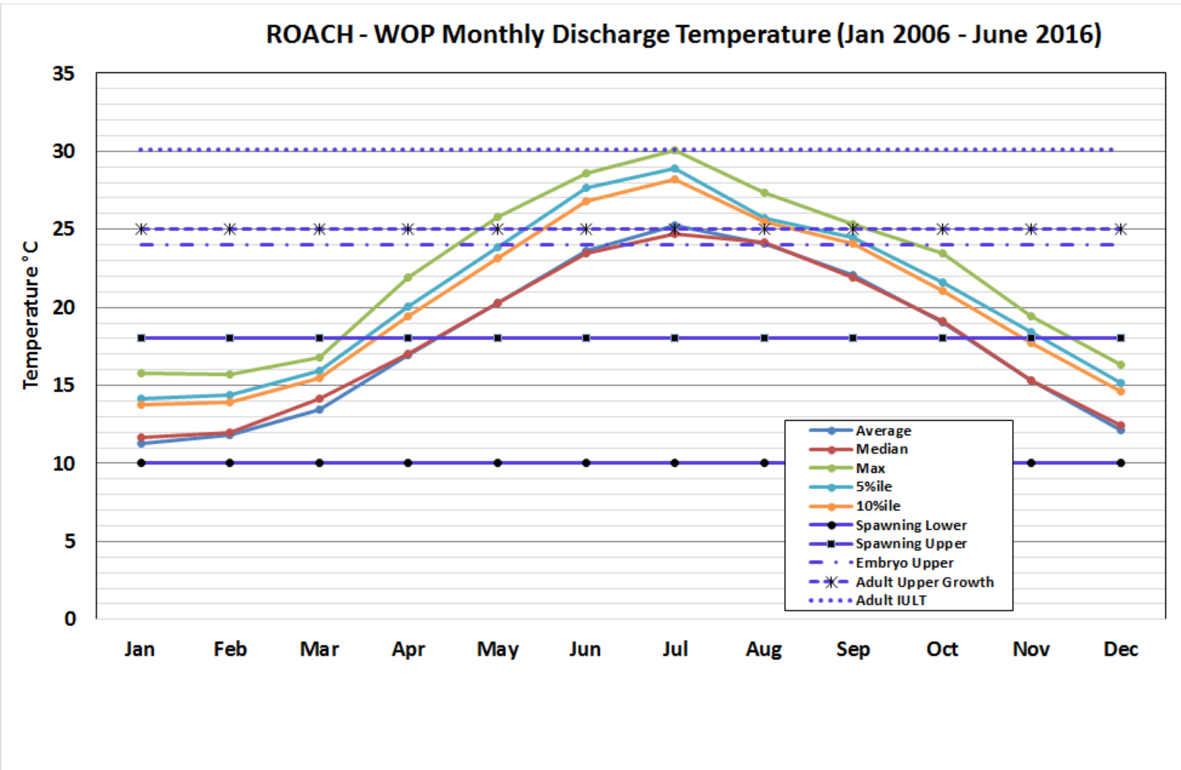

Figure 12b Roach thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

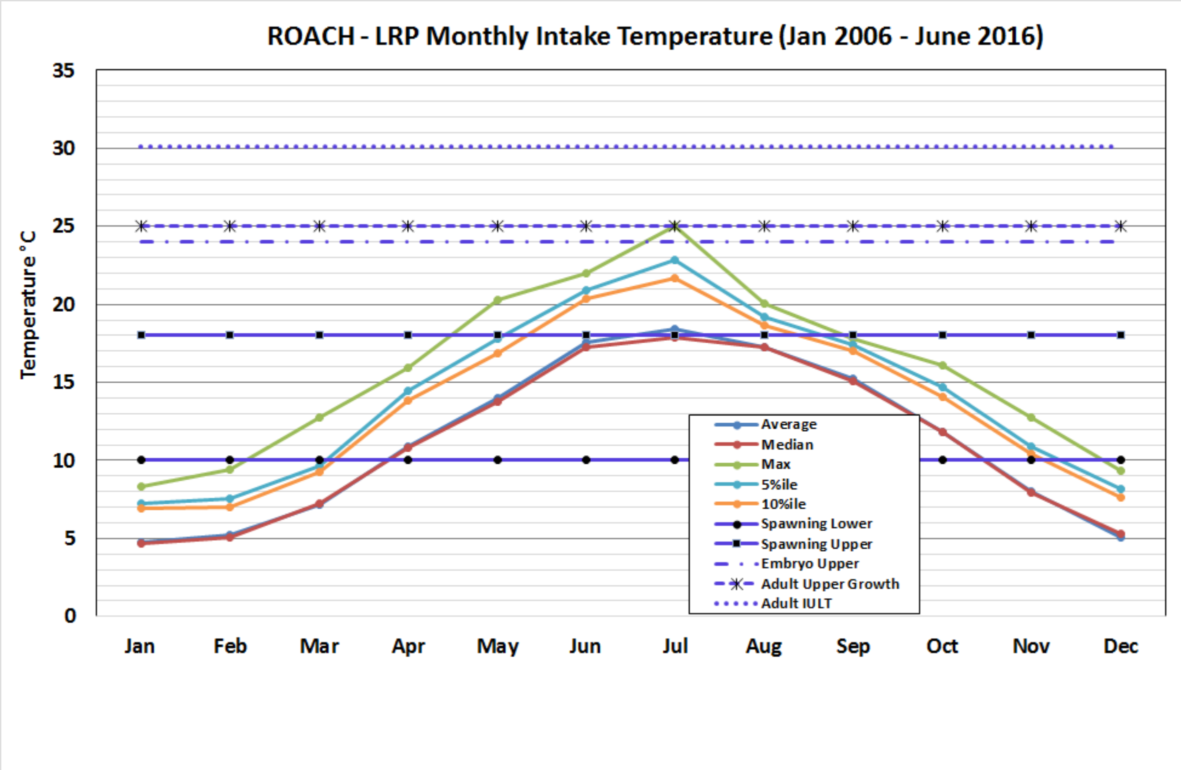

Figure 13a Roach thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

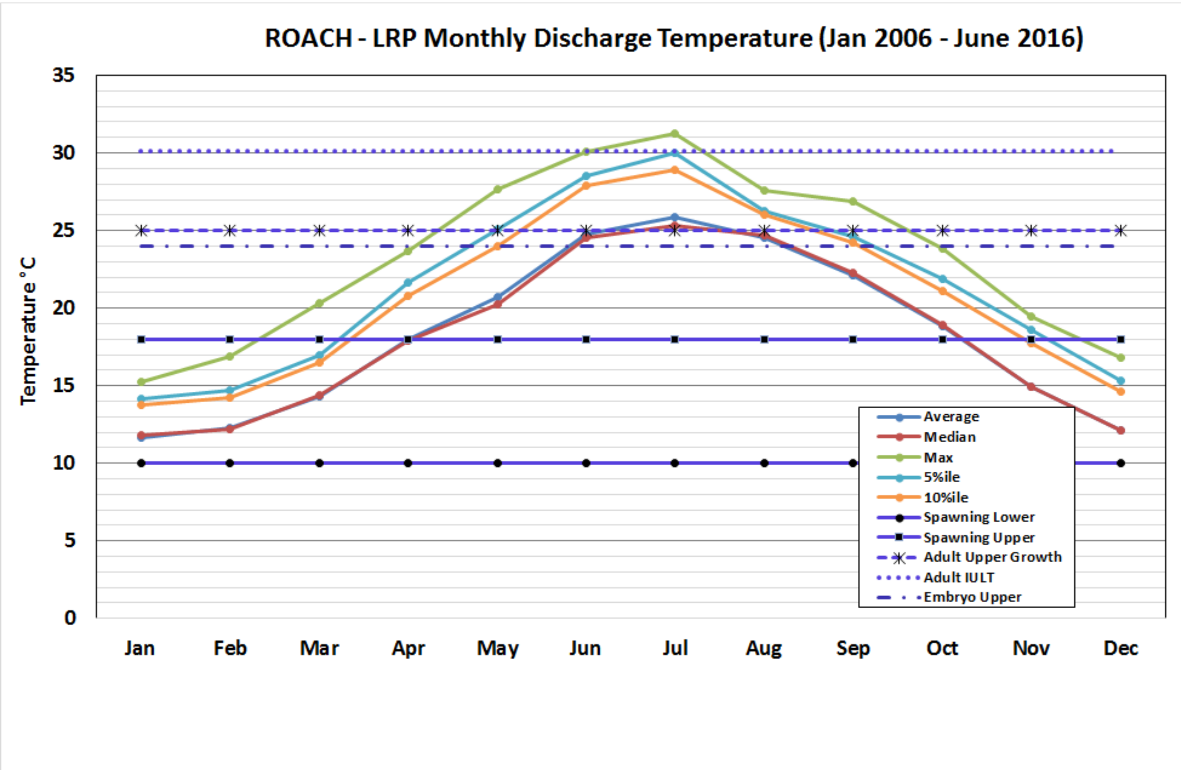

Figure 13b Roach thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Perch (*Perca fluviatilis*)

Returns from the 2010 IFI WFD fish survey at LRP and from Clonmacnoise indicate that perch were the second most numerous species in both locations. An intensive 2014 survey of Lough Ree (Delanty *et al*, 2016) showed perch to be the third most numerous species in the lake at 16% of the catch, compared to roach x bream hybrids at 21% and roach at 52%. The perch were well distributed throughout including in the northern section adjacent to the LPR lagoon. The CPUE (6.44) is considered high by Irish lake standards, which indicates that Lough Ree can be considered a good perch water.

Based on a communication from the Central Fisheries Board reported in a 2008 BIM study on perch farming, the species spawns in Ireland from early April to mid-May in temperatures from 9-14°C. This tally's with work in England which showed perch spawning in mid-May about 10 days earlier than roach at the same site (a canal in Manchester) at temperatures of 12-14°C (Nash et al., 1999) and with Maitland and Campbell (1992) that indicate that perch tend to spawn a few weeks earlier than roach.

In the Shannon at LRP and WOP, the average ambient temperatures in April are 10.9°C and 10.3°C respectively while in May the equivalent temperatures are 13.9°C and 14.0°C respectively. These data suggest that in an average year perch at both sites spawn in late April to early May (Figures 14a & 15a). Downstream of both cooling water discharges (Figures 14b & 15b), the temperatures in January, February and particularly in March would be high enough to trigger spawning, which raises the possibility that if spawning-ready perch were present in these areas in these months they might be stimulated to spawn earlier. However, plume behaviour in all of these months is likely to restrict the area of such an effect to relatively short lengths of the eastern side of both channels over 200-400m. On such a restricted spatial scale, this effect, were it to occur, is considered to be of minor to negligible significance. Perch spawning in Lake Geneva were observed to move to greater depths as the spawning season advanced to avoid warmer surface water, an effect which was most pronounced when the surface water was 14°C. This suggests that spawning perch might avoid the warmer areas while spawning. Although, perch haven't been observed spawning in the study areas, as in the case made for roach earlier, on a precautionary basis it is being taken that they do spawn in marginal vegetation at both sites both upstream and downstream of the power plants.

Based on data in the literature perch appear to have a higher upper thermal tolerance range than roach, and would therefore be unlikely to show significant avoidance behaviour downstream of the discharge at either site, except in very warm years and most likely during July at WOP and June and July at LRP. If it occurred at all, it would be most likely in the discharge canal at LRP and within 100m of the discharge in WOP. However, at this latter site there are sufficient cooler 'streams' within the flow, particular at depth, where the temperature even in the upper discharge stretch would be within the perch's tolerance range. In the LRP discharge canal the flow is more concentrated and there are fewer thermal refuges, during warm, low flow conditions, as revealed by the 2014 August 1st thermal plume survey at that site (IHD, 2014c&d). These effects can be seen as short-term, very intermittent and spatially restricted and for these reasons are unlikely to have any significant impacts even on the local population at either site.

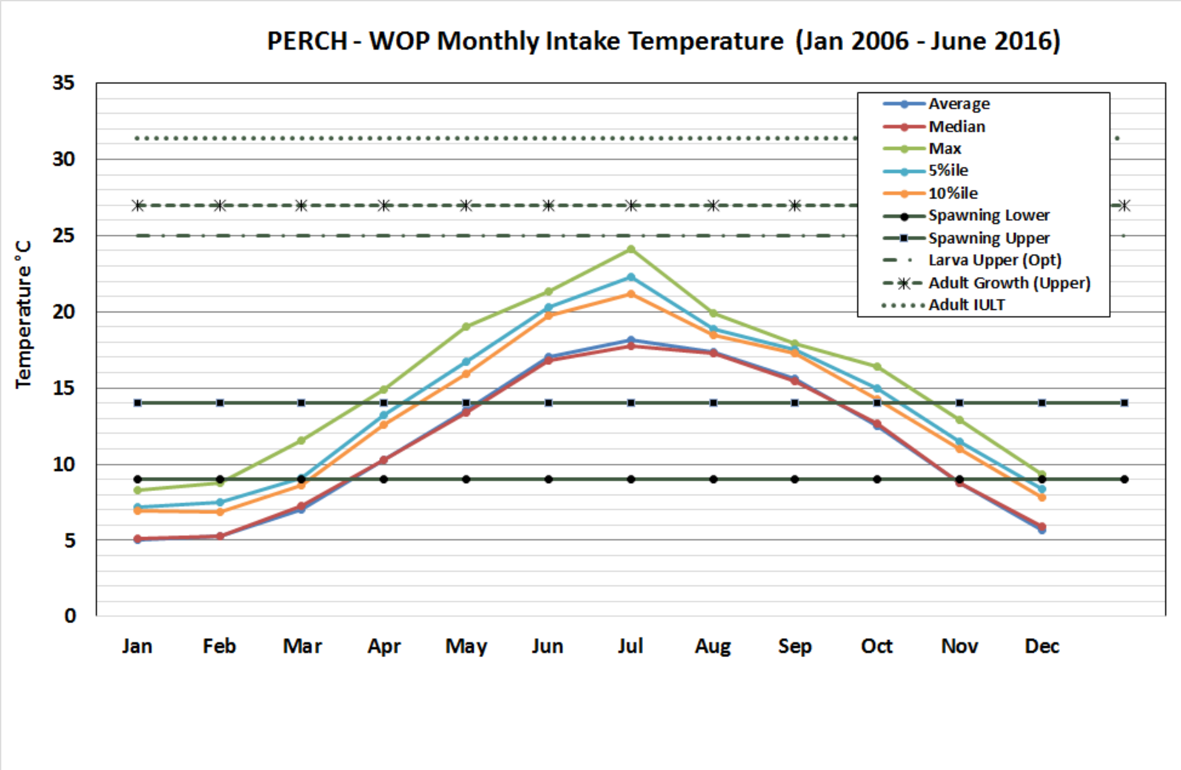

Figure 14a Perch thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

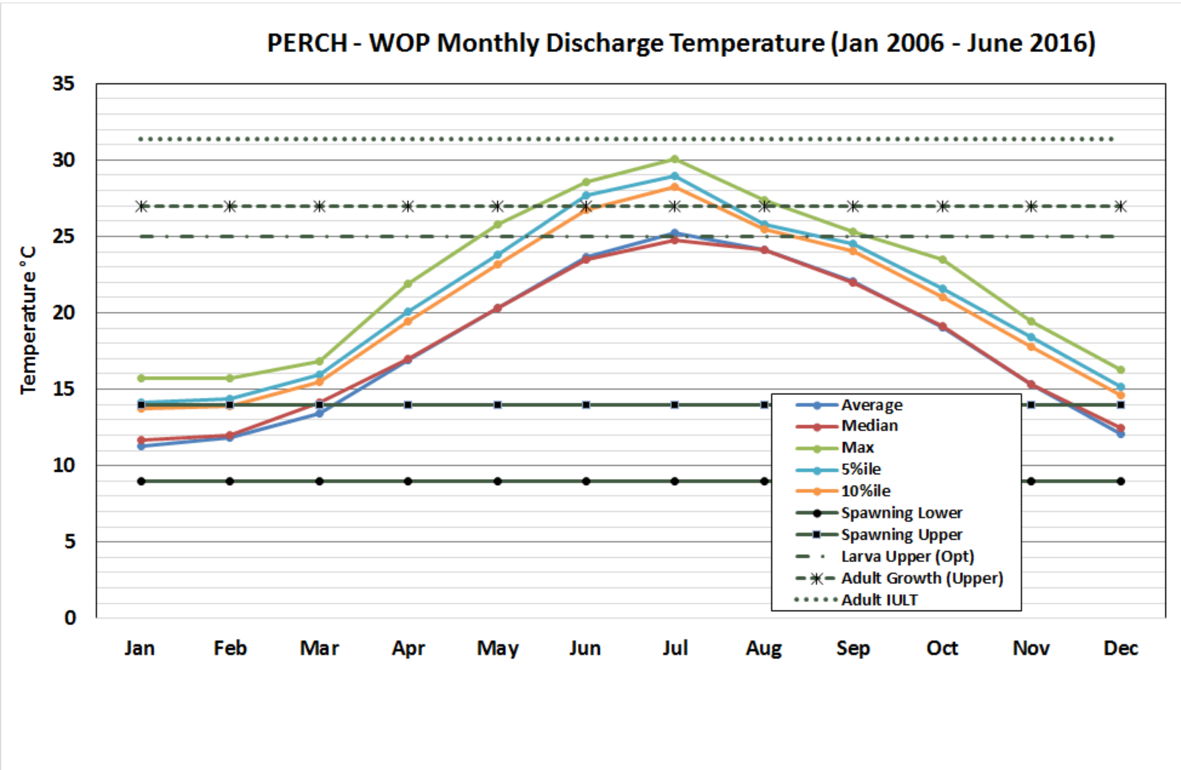

Figure 14b Perch thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

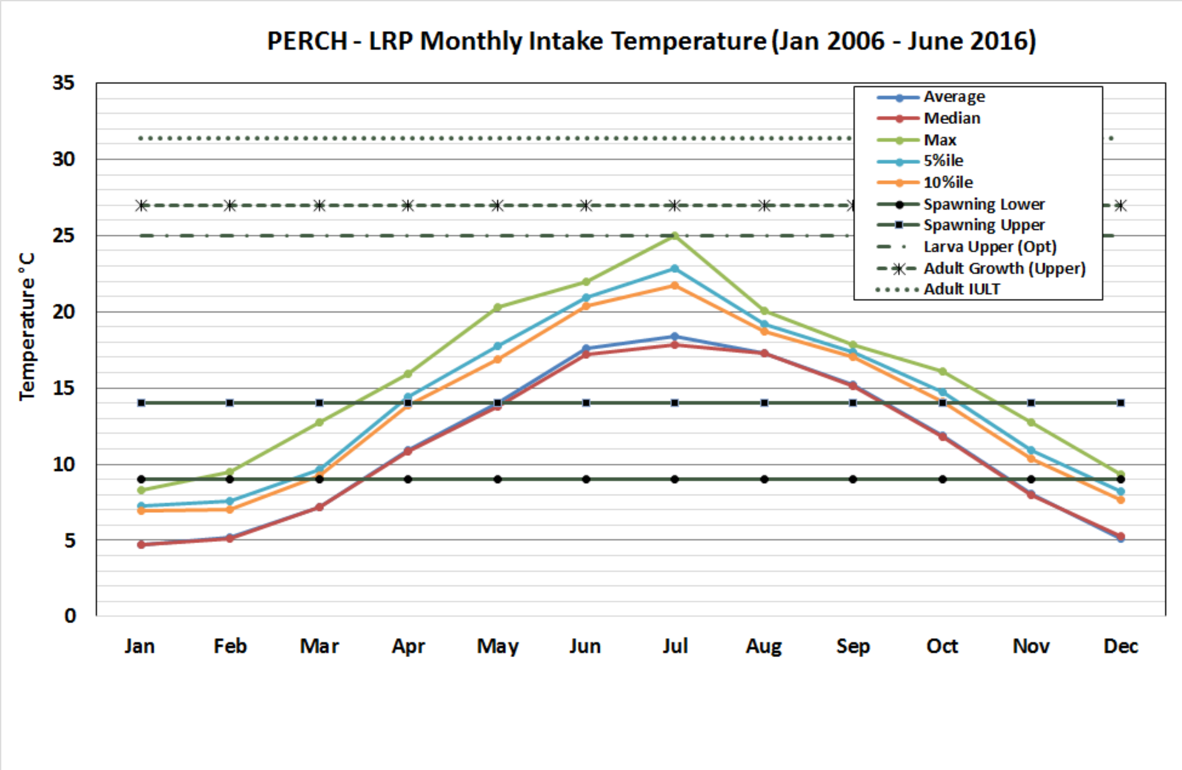

Figure 15a Perch thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

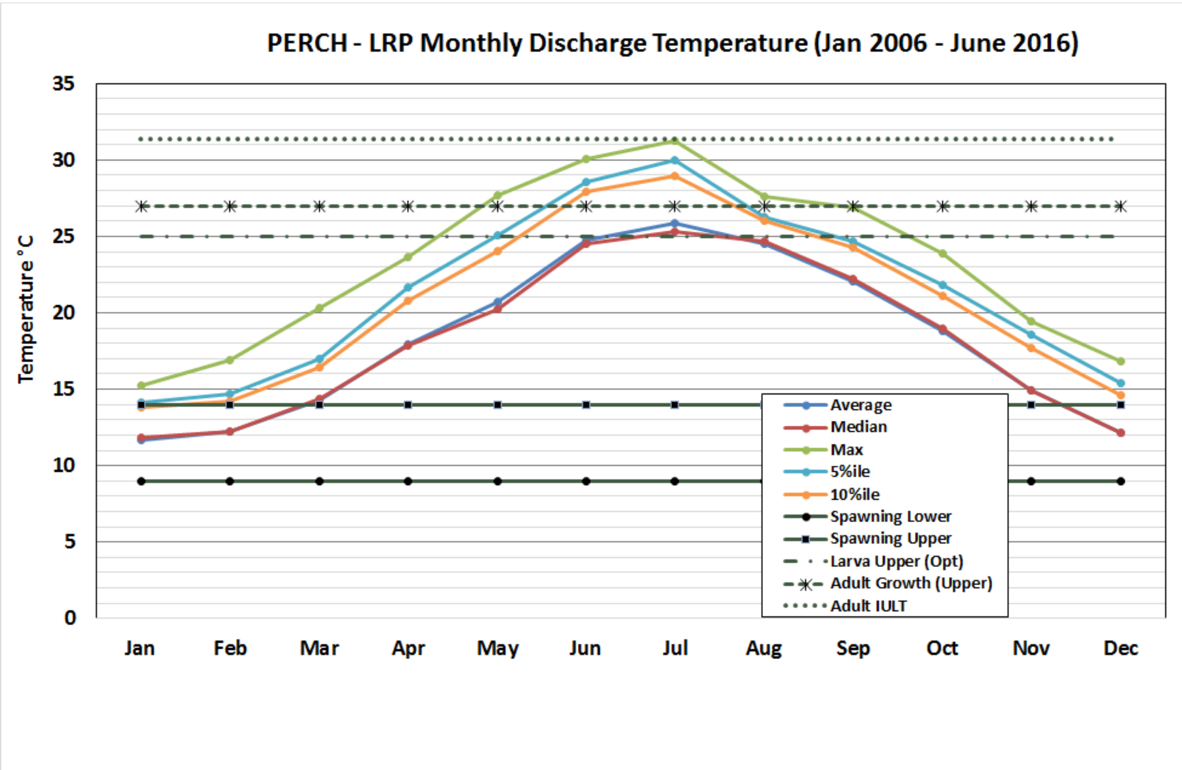

Figure 15b Perch thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Minor Components of the Fish Community at LRP & WOP

Based on the IFI WFD survey of 2010 at LRP, several species were only present in very low numbers at one or both sites. These included gudgeon, which were only found upstream of the plant (5 in total), rudd (4 fish, upstream and 1 downstream), roach x bream hybrids (2 fish downstream) and bream (1 fish upstream and 1 downstream). It seems reasonable to suggest that none of these species forms an important component of the community of either site and they will not be discussed in the same detail as the other species mentioned. It's important to note that although eel and lamprey were also present at both LRP and Clonmacnoise fishing sites in relatively small number in the 2010 survey this is thought more a reflection of the difficulty of fishing these species in deep water using electrofishing gear, especially for eel, than evidence of scarcity. They are also of greater conservation importance, than any of the other less abundant species mentioned. None of the rarer species listed above were encountered at Clonmacnoise 11.5km upstream from WOP site during the same IFI survey. It is worth noting, however, that IFI's online angling information pages (Angling Ireland) indicate that the warm water sections downstream of both plants hold rudd, bream, bream x roach hybrids and tench, all at good levels (see for example quote in box below for Lanesborough discharge canal).

`This stretch holds most coarse fish in abundance when conditions are favourable and is particularly noted for its large tench and attracts plenty of pike also in pursuit of the fodder fish present. Many specimen tench who favour warmer waters to spawn have these conditions here where they tend to congregate, best time mid-May onwards. Try the canal stretch, the point where the hot water joins up and close to the embankment down from the car park. Frequent reports of large specimens 6lbs-7lbs have been reported by anglers over the years, a number of which have been verified by the Irish Specimen Fish Committee over more recent times. Like all the other swims pike abound, so come prepared with suitable pike gear as the stretch produces large pike from time to time. Anglers often report snatch takes while coarse fishing here.

http://www.fishinginireland.info/coarse/shannon/shannonbridge.htm#hotwater

Of the species listed all have upper incipient thermal limits (IULT) in the same range of the cyprinids already discussed (roach and perch) and higher for tench and none are therefore considered likely to stand out as more vulnerable. Gudgeon (*Gobio gobio*) (Figures 16a&b and 17a&b) maybe an exception to this as they have a lower IULT (28.6°C) based on British work quoted in Alabaster and Lloyd (1980), although work in continental Europe (Poland) suggest significantly higher lethal levels (30°C +). I could find no data on their preferred spawning temperatures in Ireland, but Wheeler (1978) considers them an early summer spawner. Kennedy and Fitzmaurice (1972), collected Gudgeon eggs from a 'rivulet', flowing into the Lee Reservoir in early June and late June. They are a bottom feeding species and a therefore have a behavioural trait that will tend to protect them from the extremes of the thermal plume which in most locations has been shown to be a predominantly surface phenomenon. Despite this however, it is appropriate to assume that during the high summer months during particularly warmer years, the species may well avoid most of the discharge canal at LRP, and sections of the first 100 – 300m me downstream of the WOP discharge.

Bream (*Abramis brama*) (Figures 18a & b and 19a & b) is the only species for which there is site-specific data in the published literature relevant to one of the project sites. Bream were observed to be 'splashing in a bed of bulrushes 30 yards downstream from the cooling water outlet from a peat-fired electricity generating station' on May-15th to 17th 1965 (Kennedy and Fitzmaurice, 1968). Bream eggs were collected from the site on May 19th containing advanced embryos, the temperature was 18°C. Bream eggs, 'about to hatch', were also collected a week later (May 25th) in Lough Coosan about 25km south near Athlone where the temperature was 14°C. The latter temperature, based on the ambient temperature for LRP between 2006 and 2016 is average for May. This strongly suggests that the discharge canal at 18°C measured the previous week in the discharge canal at Lanesborough, quoted in the Kennedy and Fitzmaurice paper, was a few degrees above ambient but was nevertheless being used for spawning by the species. This suggests that bream despite their very small numbers may still spawn in the discharge canal in May. As adults, bream are quite tolerant of elevated temperatures with an upper growth optimum of 26°C and an IULT of 31.2°C. These temperatures are exceeded in the discharge plumes of both sites in the warmest years in June –August at which times, the species may tend to avoid the discharge canal at LRP and the warmers parts of the channel within the first 300m of the outfall at WOP.

Rudd (*Scardinius erythrophthalmus*) (Figures 20a & b and 21a & b) are likely to have declined significantly in the Shannon system since the early 1970's with the introduction of roach, which is now the dominant species throughout. It only formed a small portion of the fish community in Lough Ree accounting for just 1.3% of the catch (i.e. 103 individuals) with a CPUE of 0.52. According to IFI (Delanty *et al.,* 2016), this is quite high for spring-sampled lakes e.g. Loughs Arrow, Sheelin, Ennell and Derravaragh where numbers of rudd taken in surveys are usually less than 10. Their small numbers at LRP (4 upstream and 1 downstream) don't allow much to be concluded about the potential impact of the discharge on them. They have a similar IULT (31.2°C) to roach, bream and perch, so are unlikely to be impacted much differently to these two species. Kennedy & Fitzmaurice (1974) indicate that they spawn mainly in Ireland in June and July, and can be therefore be described as late spawner. Despite having a similarly high thermal tolerance to the other cyprinids of interest, its habit of feeding near the water surface would likely expose it to higher temperatures than these other species in the community downstream of the discharge which, would tend to accentuate an avoidance response during very warm weather.

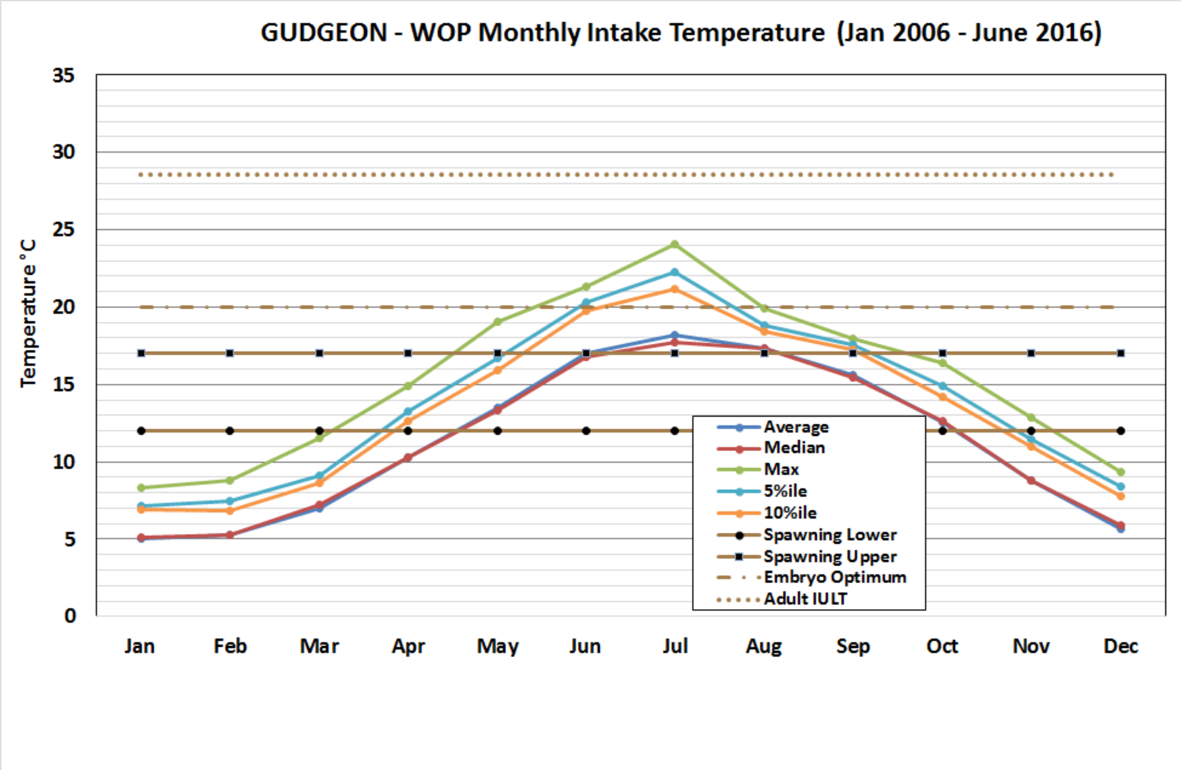

Figure 16a Gudgeon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

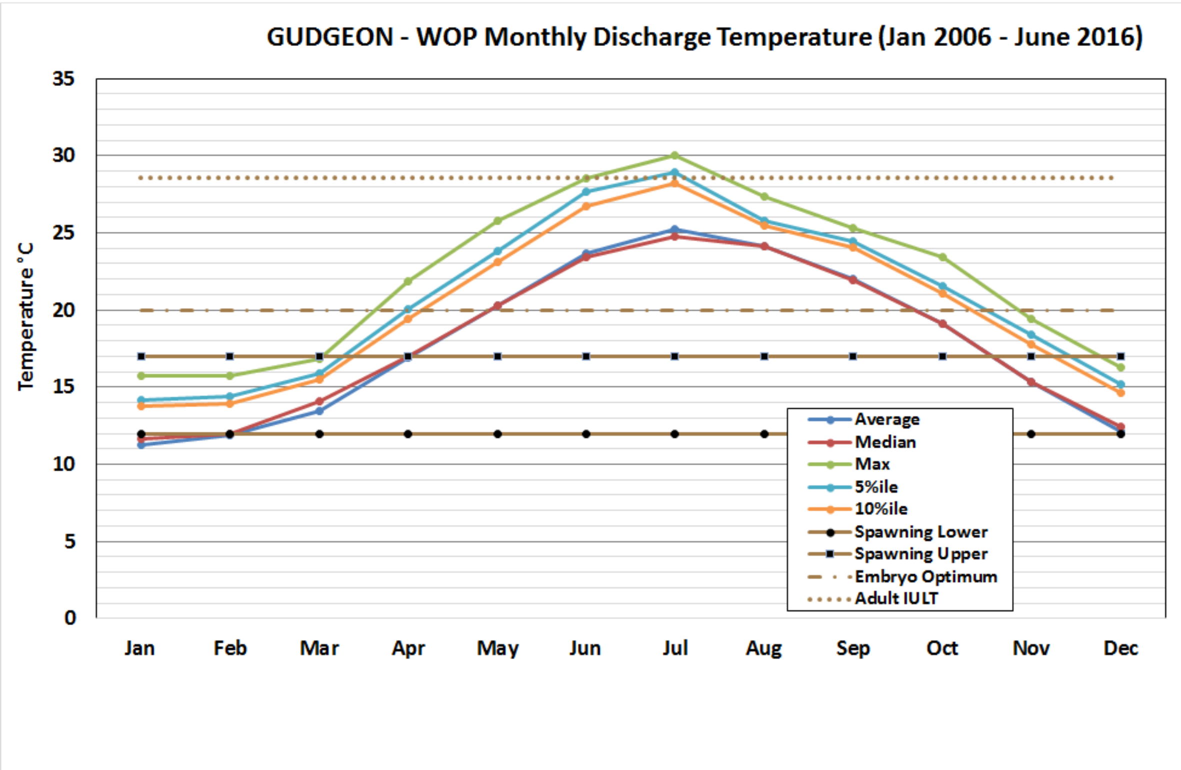

Figure 16b Gudgeon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

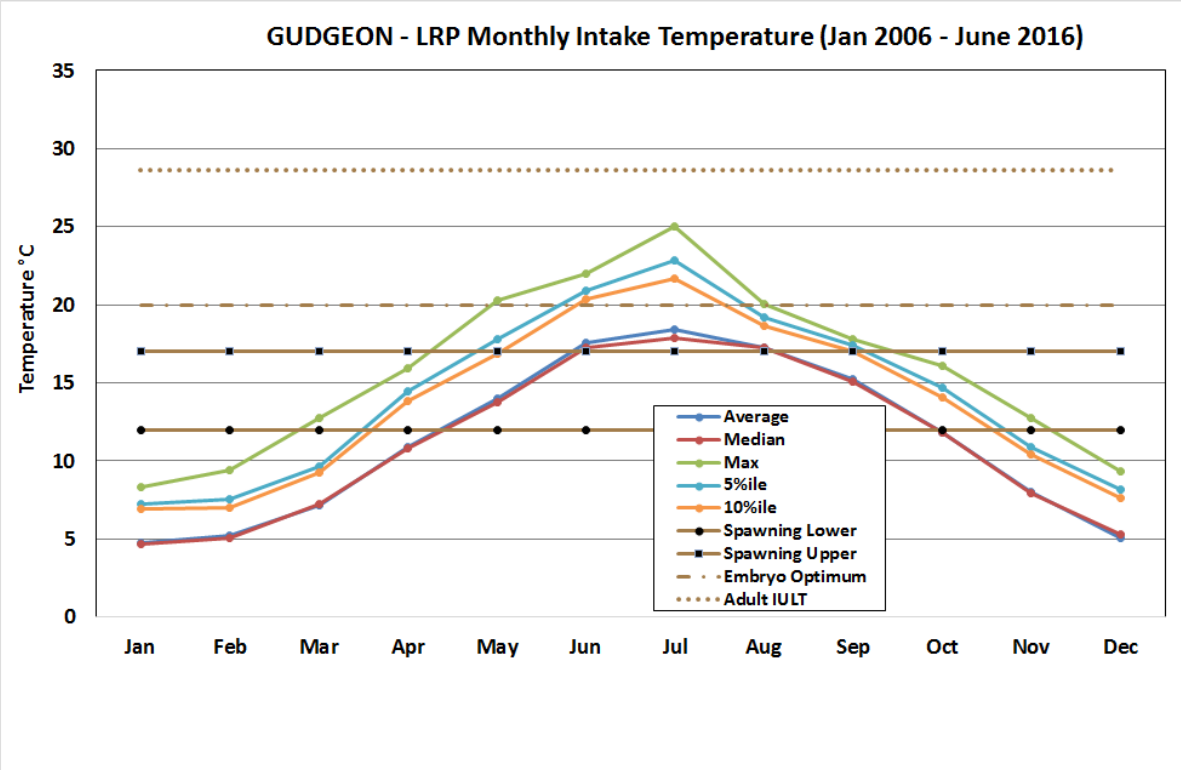

Figure 17a Gudgeon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

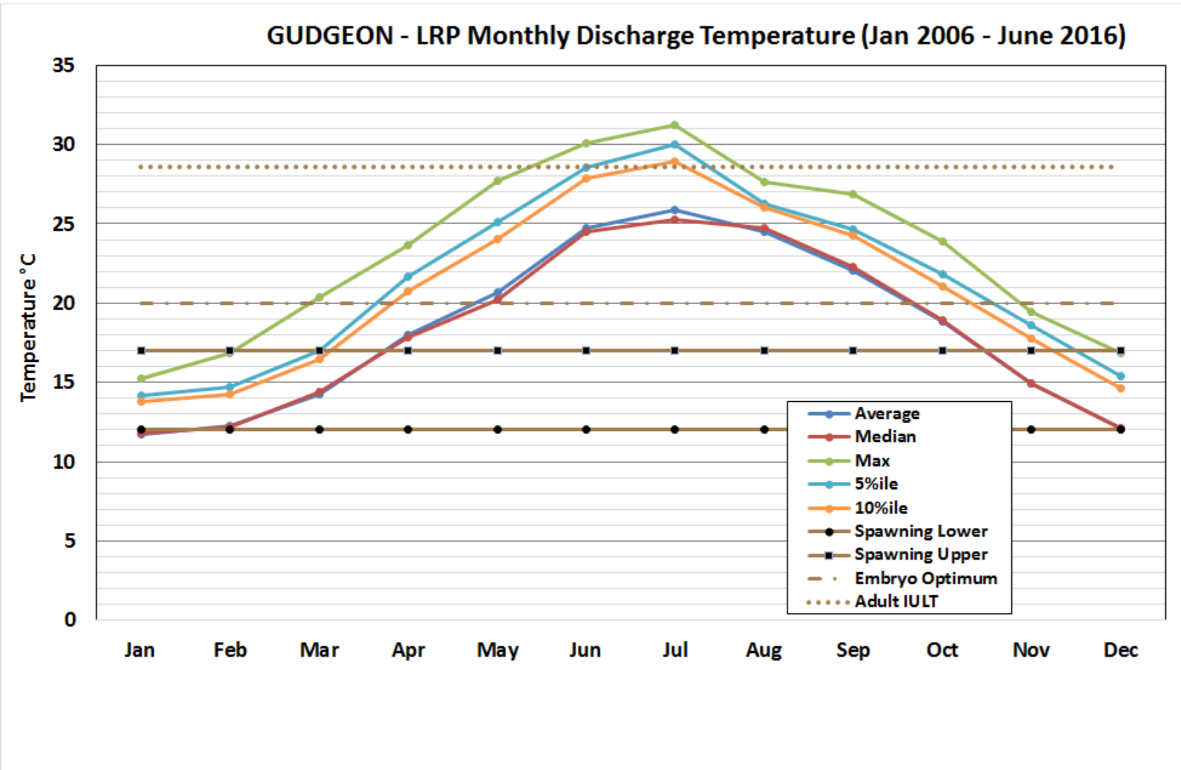

Figure 17b Gudgeon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

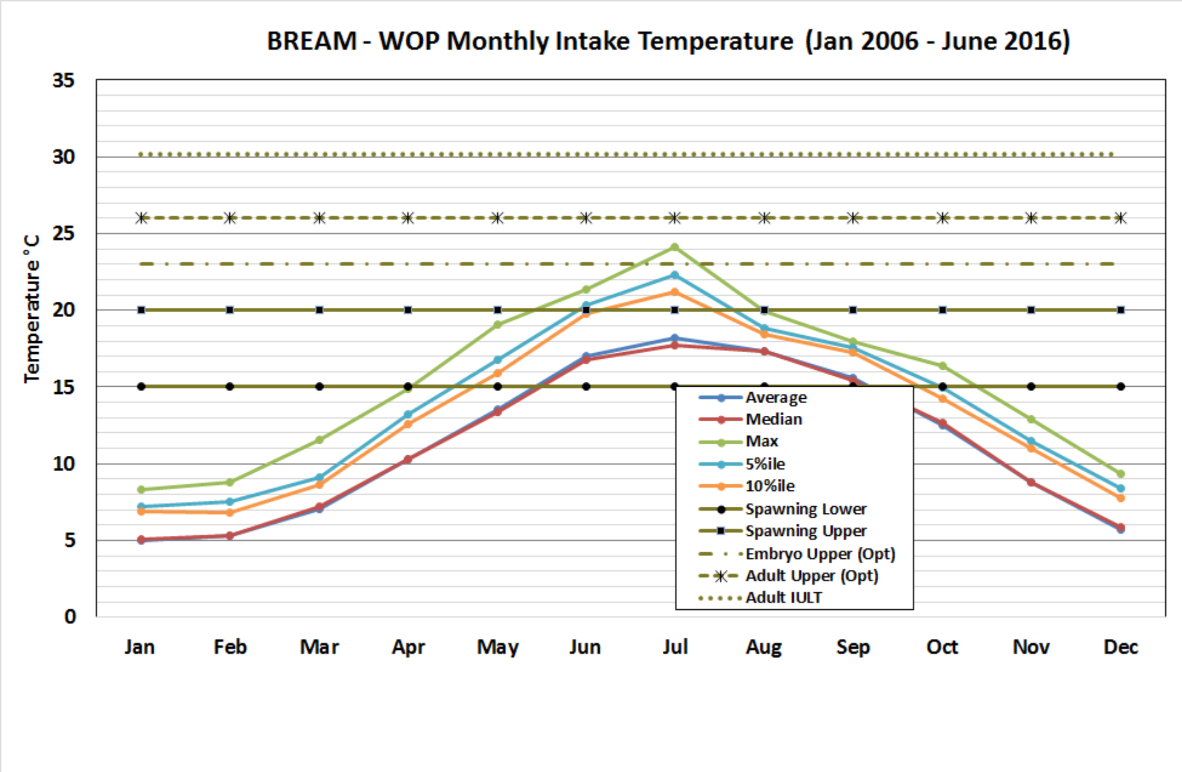

Figure 18a Bream thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

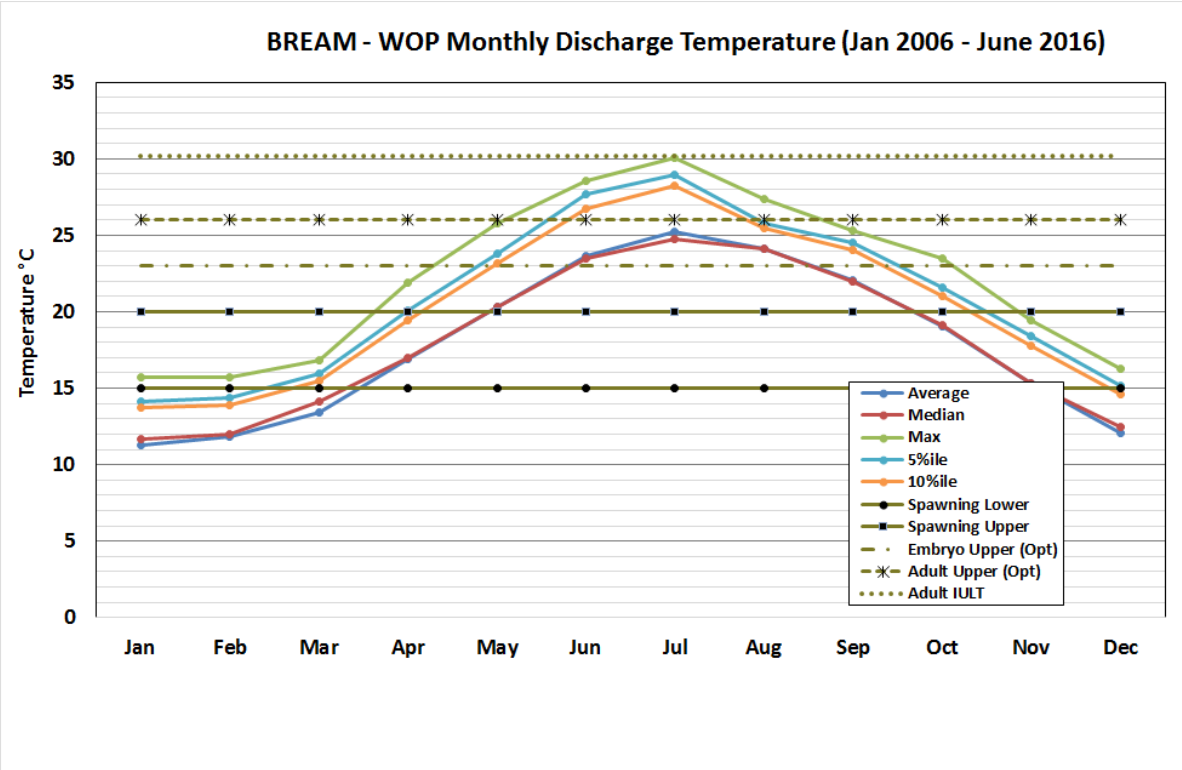

Figure 18b Bream thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

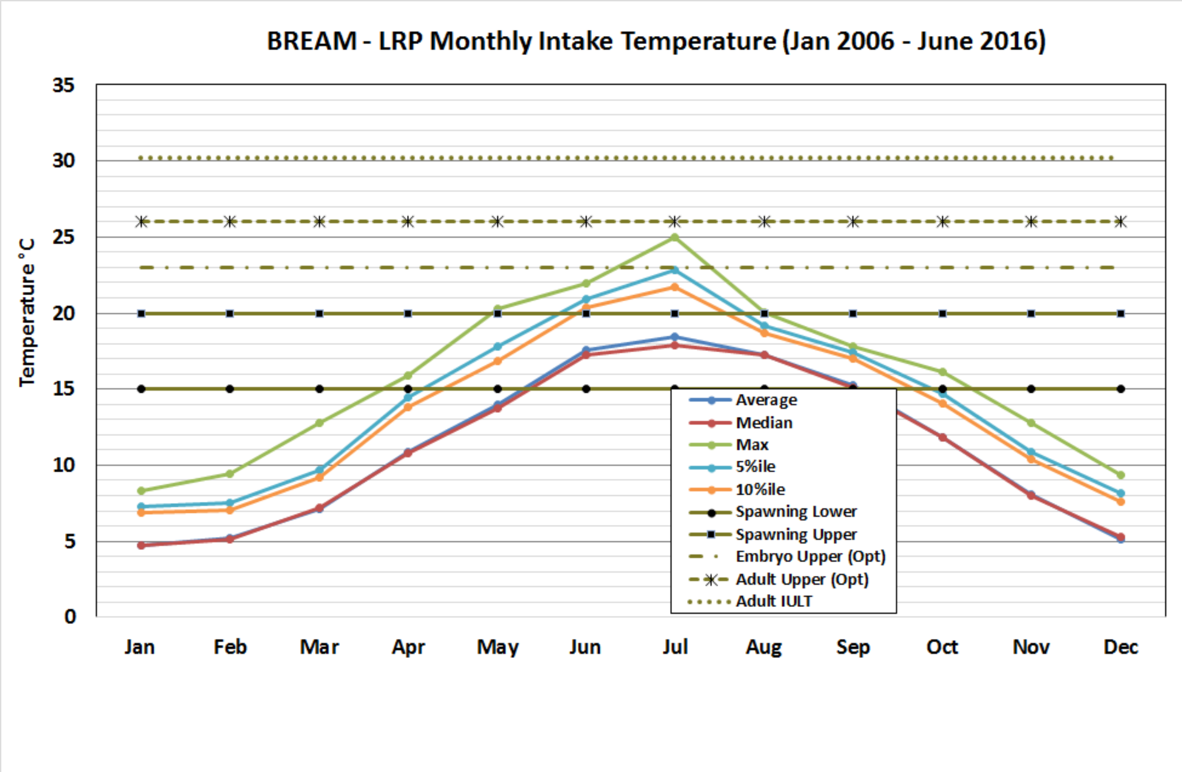

Figure 19a Bream thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

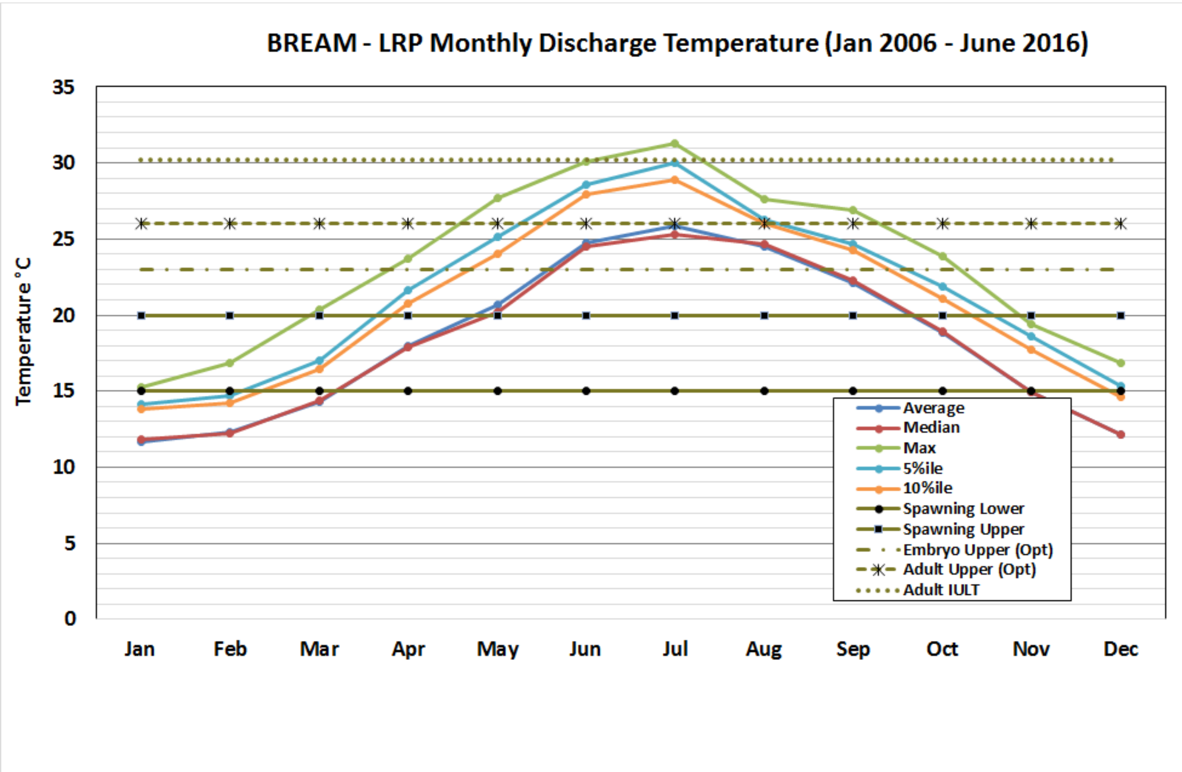

Figure 19b Bream thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

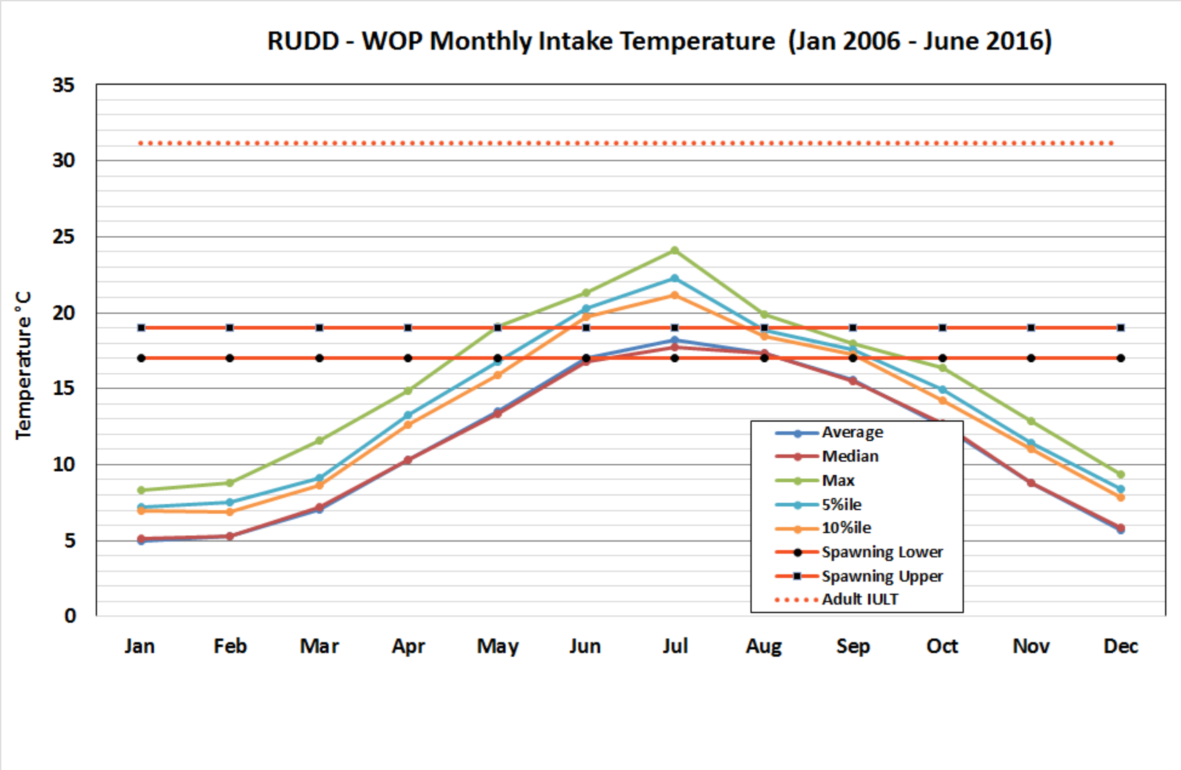

Figure 20a Rudd thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

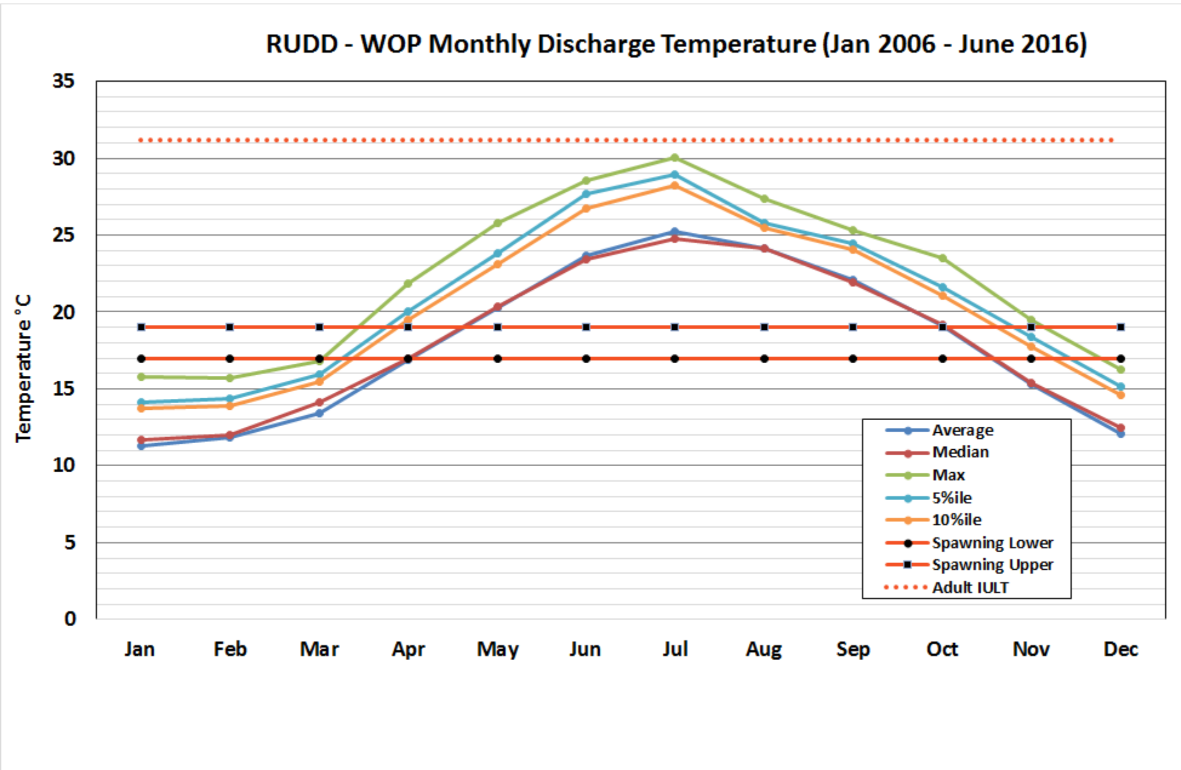

Figure 20b Rudd thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

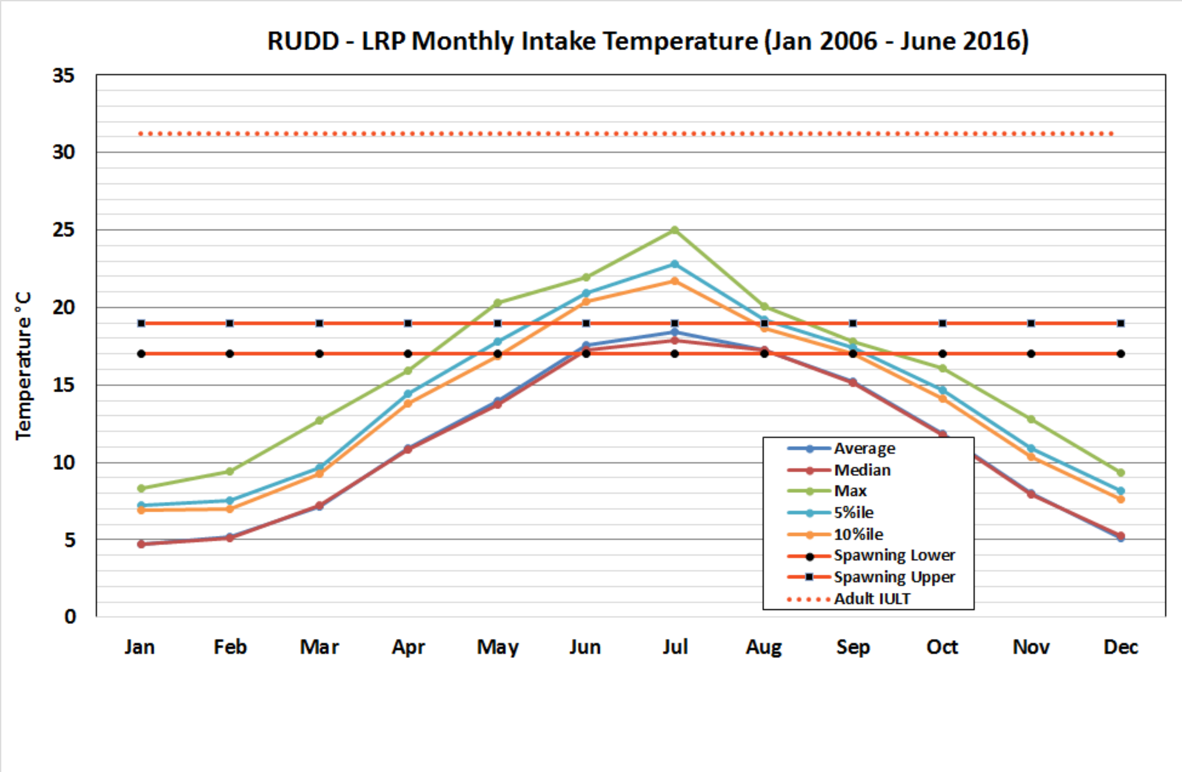

Figure 21a Rudd thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

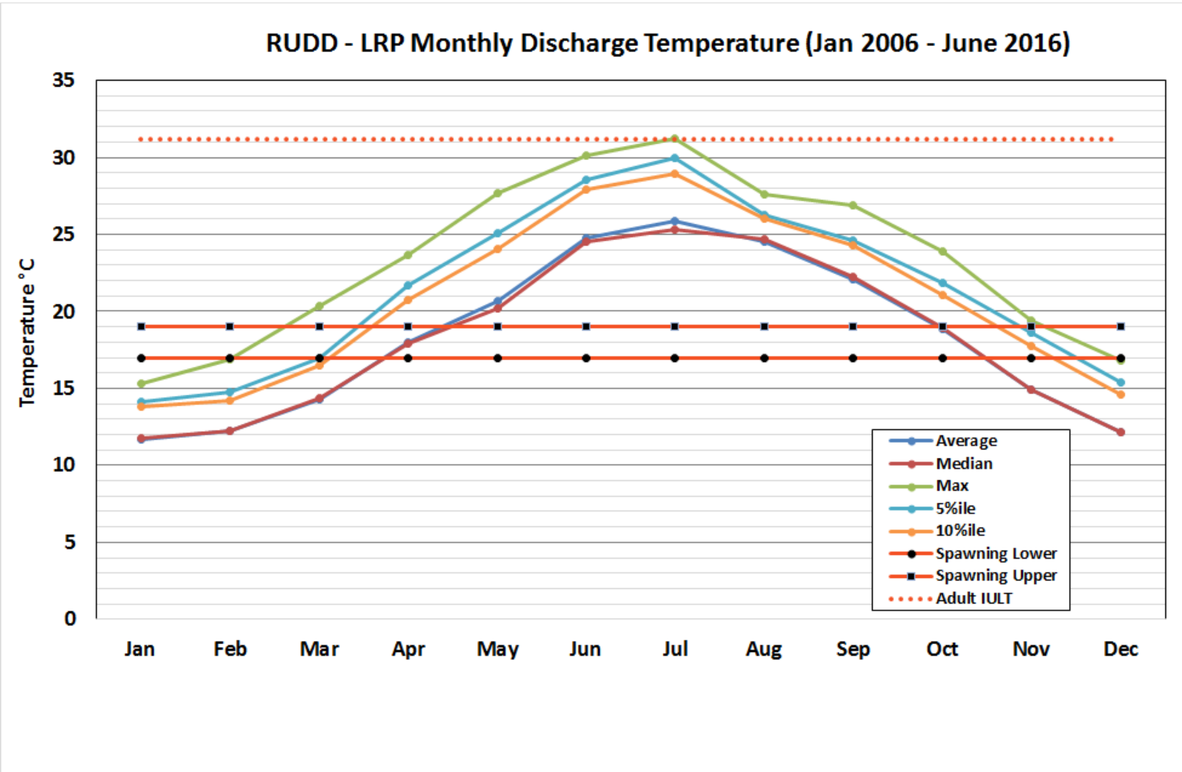

Figure 21b Rudd thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Summary

This report comprises a review of the thermal tolerances, based on a literature review, of the resident and migrant fish at Lanesborough and Shannonnbridge on the River Shannon at the sites of the Lough Ree Power (LRP) peat-fired generating station and the West Offaly Power (WOP) peat-fired station respectively. The report also addresses the potential risks posed to the fish community by the cooling water discharge temperatures and thermal loading from both plants.

At both plants cooling water is abstracted from the river upstream at a rate of ~ 4-5m^3/s and discharged downstream of each at a temperature about 7-8°C higher than the intake.

In order to assess the risks posed by the thermal discharges, historical temperature data for the intake and discharge at both plants was compiled and summarised for the period 2006-2016. For this analysis the intake temperature is taken as being the same as the ambient upstream temperature in the river at both sites and the discharge temperature is taken to be the highest possible temperature in the thermal plume. As the plume mixes and disperses downstream, the impact of the discharge temperature will reduce, limiting the degree of exposure of fish accordingly. The rate and extent of the dispersion involved and hence the degree of risk will depend in particular on the flow in the river at the time. In order to understand the horizontal and vertical spread of the plumes below the cooling water discharge of both power station locations, reports of thermal plume surveys undertaken by Irish Hydrodata (IHD) in late July/early August (2014), in February (2015) and in late-April/early May (2016) under a wide range of river flows and ambient temperatures were examined in detail.

The following fish species were selected as being members of the resident fish community or as migrants: roach, perch, pike, eel, lamprey (*Lampetra* sp.), brown trout, salmon, bream, rudd, and gudgeon. This selection was based on published data from Inland Fisheries Ireland's (IFI) Water Framework Directive (WFD) fish monitoring programme and from the ESB Fisheries Annual Report for 2015.

The thermal tolerances for one or more life stages of each of these fish species was compiled from the scientific literature. These data were used in combination with the 2006-2016 temperature data and plume behaviour data for each of the study sites in order to assess the potential risks to the fish species in question.

The upper temperature cut-off point chosen for each species was the Incipient Upper Lethal Temperature (IULT) which is the temperature at which 50% of test fish would succumb after about 16hours of exposure. Below this temperature the majority of fish would be expected to survive indefinitely. The IULT was taken to be the upper boundary of temperature tolerance for each species. Other limits examined, where available and relevant, were optimal and upper boundary growth limits etc. Particular attention was given to spawning where appropriate, as well as the period of inward and outward migration in eels, salmon and lamprey.

The historical temperature data for the intakes at both sites indicated that during the summer the LRP intake was usually about 1°C warmer than the WOP equivalent, a trend that more or less reversed during the winter and early spring. It was speculated that the presence of Lough Ree upstream of WOP may be influencing these trends. The data also showed that the warmest summer peak ambient average temperature reached 22-23°C

(Max 25-26°C), while the corresponding average cooling water discharge temperatures were in the range 29-30°C (Max 30-31°C).

During the February 2015 thermal plume survey at LRP, undertaken by IHD on behalf of ESB GWM, the plume was confined to the eastern side of the channel with warmer water also generally confined to the shallow surface layers, with attenuation to background about 400m downstream. A variation at WOP was that part of the plume flowed out on to the floodplain and travelled in parallel to the main channel to re-emerge briefly at about 800m downstream of the discharge point.

The spring (April/May) plume survey (in 2016) undertaken at both stations essentially followed the same pattern as the February survey, except that the plume occupied more of the channel at both sites, extended deeper and spread farther downstream before attenuating. Nevertheless, there was a significant portion of the cross-section of the channel toward the western bank at both sites which was either unaffected by thermal discharges or very marginally so, mainly at the downstream end of the mixing zones.

In contrast, the late summer survey of 2014 showed that under conditions of very low flow, in that case 93%'ile, the plume extended effectively from bank to bank at LRP and didn't fully attenuate until reaching the northern end of Lough Ree about 2600m downstream. At WOP, the plume followed a more zig-zag path and showed less depth penetration generally than at LRP and reached full mixing just below the first bend about 650m downstream where the residual temperature had risen to 2-3°C above ambient and remained at that level more or less until the end of the survey length at 1750m downstream of the discharge.

An examination of the published fish survey data for both sites suggests that the river could be regarded as a cyprinid water, more suited to coarse fish such as roach, perch and pike, along with eel.

The temperature tolerance data for brown trout would suggest that in warm summers the ambient temperatures upstream of the power stations at both sites would be sub-optimal in the period June-August. When the same data is considered in the thermal plume it is very obvious that conditions at both stations could be sub-optimal from as early as April and as late as October depending on whether the year was warmer or cooler. This is more pronounced at LRP where the Upper Incipient Lethal Temperature (IULT) for the species (25°C) coincides more or less with average plume temperatures in June, July and August (assuming a worst case scenario that the discharge temperature is the actual in river temperature post cooling water discharge). At WOP, this is only the case in August. These data suggest that the species is likely to be entirely absent from the discharge canal at LRP in the period June to August in most years and only sporadically present between May and October in warmer years.

Of the adult salmon that return to the Shannon each year, as few as 20% may travel past WOP and LRP in the months of June to August (when they would be exposed to the highest annual temperatures). It is suggested that in the very warmest years some of these fish might drop back down to cooler waters *e.g. Lough Der and L. Ree), until conditions improved or for an increase in river discharge that would take them up past the generating plants.. Such delays are not uncommon in the species and they don't automatically mean that the fish would have a reduced fitness to spawn later on.

It is thought that most outwardly migrating smolts descend to sea in the period mid-March to mid-May. However, as smolts are sometimes still observed upstream of the dam at Ardnacrusha up to mid-June some late migrants may still be passing the plants at that stage also. Based on the findings of the spring and early summer plume surveys it is confidently expected that the majority of these smolts would descend past both generating plants keeping to the western, thermally unaffected, side of the channel. If however there was an unseasonably low water level combined with warmer than usual temperatures this might slow the swimming speed of smolts which has been shown to be reduced by over 80% at temperatures greater than 17°C. This in theory might make them more prone to attack by fish and avian predators as they pass down through both sites. Nevertheless, this risk is considered to be a minor one because of the likely infrequency of its occurrence and the small portion of the smolt cohort likely to be exposed in any given year.

Based on the literature review, eel are likely to be one of the most thermally tolerant species in the community at both sites. Most silver eels migrate to sea between August and February on the Shannon once there is a rise in water levels and for this reason and their general bottom moving habit, this stage in life cycle is believed not to be at risk from the thermal discharges at either site.

Resident eels because of their relatively high thermal optima and IULT, combined with their bottom-dwelling habit are believed to be at very low risk of thermal stress except in the very inner portion of the discharge canal at LRP in the warmest summers during June and July when there might be some localised avoidance. This effect is unlikely to be significant over the full period of the freshwater residence of any given individual and negligible at a local population level.

Very little temperature tolerance data was found in the literature for lamprey. That which was found relates to river lamprey and sea lamprey, neither of which is expected to be present in the study sites except perhaps in extremely low numbers. The temperature tolerance for river lamprey was used as a proxy for that of the congeneric brook lamprey which is the only lamprey known to be present at the two sites. The ammocoetes of the species live for at least 3 years in soft sediments before metamorphosing into migratory adults. Overall, the temperature data at the sites suggest that there might be intermittent displacement of ammocoetes and or a possible reduction in their growth rates in areas of suitable habitat within the discharge canal at LRP and within the first 300m downstream of the WOP discharge, during very warm summers. However, bearing in mind the very wide distribution of the species (brook lamprey) throughout the Shannon system, that level of potential impact, were it to occur, is considered minor to negligible.

Pike is an important component of the fish community at both sites. It has a relatively high adult IULT (30.2°C) and upper growth limit (26°C) which means that it is quite thermally tolerant and therefore likely to be little affected by the thermal discharges in average temperature summers. However, in warmer years, pike may avoid the discharge canal during periods of low flow when the degree of temperature attenuation along the canal would be relatively minor (1-2°C) as seen in the August 2014 thermal plume for the site (IHD, 2014c&d).

The current report also considers whether the warmer temperatures in the plume at each plant might cause pike to spawn earlier in the affected stretches than they would in ambient temperature conditions. However, this wasn't considered to be a very likely eventuality because flow conditions would be likely to restrict the plume from reaching the lagoon downstream of LRP which is thought to be the most likely place in the area for pike to spawn, at that earlier time of year i.e. January-early March. The likelihood that some pike might spawn in the thermal flow that was observed to spread out onto the floodplain downstream of WOP in February 2015 is also possible, as pike are known to spawn in such locations. Overall, the possibility of some marginal advancement in the time of spawning of pike downstream of both LRP and WOP cannot be ruled out but if it does occur it is considered likely that it would only likely affect a very small portion of the population in either reach and therefore not be associated with any measureable adverse impacts.

Roach is the dominant fish species in terms of numbers at both sites and is also the most numerous fish in Lough Ree. It is thermally tolerant and has been recorded in 'relatively high numbers' in the River Trent in the UK when the temperature was 27.5°C. It was the main reason in the past that the Lanesborough discharge canal was such a popular spot for coarse anglers. During the very warmest years, July temperatures in the cooling water discharge approach the IULT for the species (31.1°C) at WOP and exceed it at LRP. Under these conditions some avoidance of the discharge canal and the inner section of the lagoon i.e. within the first 600m downstream of the discharge point, might occur. Due to the nature of the plume and its vertical distribution at WOP the degree of avoidance at that site, should it occur, is thought likely to be less pronounced. Should they occur, these impacts are likely to have very little significance for the roach population, even at a local scale due to its dominant position numerically.

Research on roach in Belgium on the Meuse showed that the species spawned 3 weeks earlier in temperatures that were 2-3°C above ambient due to the thermal discharge from a power plant. It was considered possible that this could also occur on the Shannon at both sites along the eastern side of the channel extending 300-600m downstream at LRP and 200-300m downstream at WOP giving rise to an early to mid-April spawning of affected fish that would otherwise be expected to spawn around mid-May. In the context of the size and extent of the roach population within the Shannon at both sites, these impacts, should they occasionally arise could be described as negligible.

Perch were the second most numerous species taken in the IFI WDF fish survey in 2010 at LRP and they are believed to be at the same level in the population at WOP based on the IFI's findings for the same survey in the Clonmacnoise stretch 11.5km upstream. Adult perch are slightly more thermally tolerant than roach according to the literature, and are therefore unlikely to encounter any thermal stress downstream of the thermal discharges except in the very warmest summers close to the discharge points. If it occurred at all, it would be most likely in the discharge canal at LRP and within 100m of the discharge in WOP. These effects can be seen as short-term, very intermittent and spatially restricted and for these reasons are unlikely to have any significant impacts even on the local population at either site.

Based on data for spawning times in the literature, perch at both sites would be expected to spawn sometime from late April to early May. Downstream of the discharge points some early spawning, perhaps in March or even earlier cannot be ruled out. However, plume behaviour in all of these months is likely to restrict the area of such an effect to relatively short lengths of the eastern side of both channels for a distance of about 200-400m downstream of the discharge points. On such a restricted spatial scale, this effect, were it to occur, is considered to be of minor to negligible significance.

Three other species, gudgeon, bream and rudd were recovered in very small numbers by IFI at LRP in their 2010- survey at LRP. However, due to their very low representation at the site it is unlikely that the thermal plume will have measureable adverse impacts on their numbers. These species along with tench, in particular, have been mentioned on the IFI angling web site (Angling Ireland) as being prominent members of the resident fish community downstream of the cooling water discharges of both plants. It is worth noting that bream and rudd have thermal tolerances in the same general range as roach and perch, with tench having a higher tolerance, and none of them are therefore likely to suffer significantly greater adverse impacts than those species. Gudgeon would appear to be less tolerant, but this may be an underestimation.

Conclusions

The current review and risk assessment would suggest that the thermal discharge at LRP and WOP are likely to have only minor impacts on the resident fish community under average conditions of flow and temperature in any given month. In some warmer years during conditions of low flow, particularly in the period June-August, all fish species may exhibit some avoidance behaviour of the upper 300-400m downstream of the station outfall at LRP, especially in the discharge canal and in the first 100-300m downstream of the WOP discharge. In general this effect would be expected to be more pronounced at LRP where slightly higher summer temperatures seem to be the norm and flow in the discharge canal is more concentrated. As trout have been shown to be the most thermally sensitive member of the Shannon fish community, any that may be present downstream of the discharges under these conditions are likely to exhibit the greatest avoidance behaviour.

Out-migrating silver eels are very unlikely to be adversely affected by the discharges because of their mainly late autumn to early spring migration window and the propensity for the greatest rates of migrations to be accompanied by increased discharge in the river.

In the warmest years where these coincide with low flows, a small portion of the returning adult salmon population may be delayed in their upstream migration downstream of both plants. The vast majority of out-migrating salmon smolts are likely to descend past both plants without interruption. There is a slight possibility that during warmer and lower than usual flow conditions in May or early June a portion of the smolts may be exposed to an increased risk of predation by fish or birds due to a temperature-induced reduction in swimming speed. Neither the potential impacts on adults nor that on smolts is likely to result in a significant negative impacts on the population given that only a very small portion of the population should be affected in any one year and the occurrence, especially in relation to smolts is likely to be rare.

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Response to EPA Observations on: ***Shannon Power Stations Literature Review of Potential Fisheries Impacts (July 2016)***

(Gerard Morgan - Aquatic Services Unit)

Commissioned by: ESBI

Undertaken by: Aquatic Services Uni (UCC)

September 2019

Introduction

The following were the observations on the literature review provided by the EPA in consultation with Inland Fisheries ireland:

Following a review of the report submitted and consultation with Inland Fisheries Ireland, it is recommended that the following be added to the literature review: (1) Effect of thermal plumes on the migration of diadromous fish species –is there any information on thermal plumes performing as barriers to fish migration. (2) Have any radio tracking studies been undertaken to assess the potential negative effects of thermal plumes on fish passage in freshwater or to assess fish behaviour associated with thermal plumes (3) If thermal plumes have caused delays in migration, what were the effects of these delays on the fish species. Did they have any negative impacts such as exposure to predation and other hazards, genetic fragmentation, etc. (4) There was also no mention of pollan in the literature review, it is known that pollan do migrate out of the lakes on the Shannon, so it may also be worth including a small section on this species. Please provide the revised literature review report by 30th September 2016.

Response

(1) Effect of thermal plumes on the migration of diadromous fish species –is there any information on thermal plumes performing as barriers to fish migration.

I have been unable to locate any reference in the peer-reviewed literature, despite searches in a number of large online academic databases (including Web of Science, Science Direct and JSTOR), to thermal plumes performing as barriers to diadromous fish migration, either for anadromous or catadromous species. Nevertheless, it is important to point out that every site should to be assessed on its own particular site characteristics in terms of watercourse hydromorphology and discharge rates, seasonal average and peak ambient water temperature, as well as the volume and thermal load of the discharge. In effect this means that were there to be a reference to a potential migratory barrier at any given site due to a thermal discharge, it wouldn't follow that there would also be one at the Shannon sites.

(2) Have any radio tracking studies been undertaken to assess the potential negative effects of thermal plumes on fish passage in freshwater or to assess fish behaviour associated with thermal plumes.

I have been unable to find any reference in databases of internationally peer-reviewed literature to radio tracking studies dealing with the negative effects of thermal plumes on fish passage or fish behaviour.

(3) If thermal plumes have caused delays in migration, what were the effects of these delays on the fish species. Did they have any negative impacts such as exposure to predation and other hazards, genetic fragmentation, etc.

As I have indicated in response to Items 1 and 2 above I have been unable to find any data in the peer-review literature in a number of large on-line databases of peer-reviewed literature specifically dealing with the delays caused by thermal plumes. However, there is a considerable body of literature which deals with the impact of elevated temperatures on salmonid migration and these data can provide us with some useful information in responding to the questions above.

In a recent detailed review, Fenkes *et al.,* (2016) address the potential impacts of 'migratory difficulty' including warmer waters and altered flow conditions on the reproductive success of salmonid fishes. They point out that because salmonids don't feed after they enter freshwaters, they 'rely entirely on endogenous energy stores to fuel return to their native spawning sites and reproduction on arrival. Metabolic rates and cost of energy en-route increase with temperature and at extreme temperatures, swimming is increasingly fuelled anaerobically, resulting in oxygen debt and reduced capacity to recover from exhaustive exercise' In effect, thermal changes and hydrological barriers both affect the amount of energy required to reach spawning sites which in turn reduces the energy available for other aspects of reproduction such as reproductive competition (which impacts on mating success) and gamete production. They note for example that thermally challenged salmonids produce less viable gametes. Overall however, they conclude that there is a gap in our knowledge when it comes to assessing how energetically depleted fish that successfully arrive on spawning grounds fare subsequently. In other words arrival at the spawning ground is just the first essential step, after that there must be successful mating, spawning and survival of viable embryos that will eventually recruit to the population. The Fenkes *et al.*, review has been prompted by the fact of climate change and urbanisation and its effect on water temperatures and current flow velocities in river systems globally.

Much of the literature on the impact of increased water temperatures relates to the elevated temperatures caused by climate change in North American rivers, many of which are heavily regulated, and the effect of such changes on the survival of migrating Pacific salmon in particular. Some of these studies have documented high mortalities among adult migrants in years with higher than normal temperatures (2-4°C above normal) e.g. Mathes *et al.,* (2010). The latter study, dealing which sockeye salmon (*Oncorhynchus nerka*) and using radio tagging techniques showed differential mortality rates among early and late run stocks, in what is a very complex and large river system (the Fraser River) in British Colombia. The study also alluded to the significance of accumulated exposure to temperature during migration in terms of degree days and how that has been shown above a certain value to increase the susceptibility to certain pathogens. Just to clarify, these studies relate to ambient, elevated temperatures and are unrelated to thermal discharges.

In another radio tracking study, this time on the Klamath River in northern California, Strange (2010) showed how adult Chinook salmon (*Oncorhynchus tshawytscha*) can continue to migrate up river in mean daily river temperatures that ranged from 21.8 to 24.0 °C (mean = 22.9°C) and during a whole week of migration experienced a mean average body temperature of 21.9°C with a minimum average daily body temperature of 20.6°C and a maximum average daily body temperature of 23.1°C. The author concludes that temperatures above these maxima completely block migration in nearly all circumstances. Strange (2010) points out that the upper thermal limits to adult Chinook salmon migration noted in his study are substantially higher than those previously reported in the literature, (21°C reported as the upper limit for migration in the species). The author speculates that differences in study methods and study circumstances might indicate that the previous maxima reported for the species could be open to question. What the study shows is (1) that there is an upper thermal limit to migration but (2) that species can migrate for sustained periods (a week or more) at or close to that limit. It is important to bear in mind however, that these upper thresholds vary between salmonid species and Atlantic salmon are more thermally tolerant than Pacific salmon (Jonnson and Jonnson, 2009).

A more recent study, using passive tracking (with PIT tags), dealing with movement of Atlantic salmon parr in high ambient river temperatures (Dugdale *et al.,* 2016) on the Atlantic coast of Canada reveals that parr moved toward cooler water plumes discharging from a 1st and 2nd order stream into a larger tributary with higher temperatures when average temperature reached 24.8 °C in the latter. In this scenario the authors suggest that fish close to a cooler water refuge will utilise it more frequently and readily than fish at a greater distance but that as the temperature continues to rise even fish at greater distance would be forced to actively seek thermal refuges. Which is why they noted that movement of more distant fish from the main stem of the river toward the thermal refugia in this tributary stream wasn't detected until a mean temperature of 29.0°C +/- 0.8 °C occurred. Given that this latter temperature actually exceeds the upper incipient lethal temperature reported for the species (27-28°C) (i.e. temp that 50% of the fish would survive after a 7-day exposure period) shows that acclimated fish can tolerate high ambient temperatures, at least for short periods. The study also suggests that fish will travel significant distances (at least 1.6km in that study) to find cooler water. In relation to the fact that the parr in this study were able to move and search out temperature refugia even at temperatures known to reduce the swimming speed of some salmonids, the authors speculate that the salmon in this particular river may be better adapted to tolerate higher temperatures. Nevertheless, the main point here is that salmon and salmonids in general have been shown to actively seek out cooler water plumes when the ambient temperature rise above a certain threshold and that they will travel significant distances to find them. The study also confirms that Atlantic salmon are the most thermally tolerant of the salmonids.

The implications of the foregoing examples for the movement of salmon past the Shannon Power Stations are as follows:

(i) Once ambient temperatures reach around 23-24°C Atlantic salmon may begin to seek temperature refuges with the likelihood of refuge seeking activity increasing with increasing temperature above this range. This means that migrating fish could gravitate to deeper water and to cooler water streams within the channel, which at Lanesborough (Lough Ree Power) would be on the western bank of the river on the opposite side from the cooling water discharge and at Shannonbridge (West Offaly Power) seems to undulate over and back across the channel downstream of the thermal discharge. However, salmon on spawning migrations can and do swim through water temperatures at or close to their upper temperature threshold for migration or in certain cases (Strange 2010) above temperatures previously reported as marking that limit. Furthermore, we can see that from the study on salmon parr by Dugdale *et al.*, (2016), salmon can still swim close to their IULT in the wild. In such a scenario, adult salmon may just continue to migrate through the relatively very short affected stretches at Lanesborough (LRP) and Shannonbridge (WOP) continuing to spawning areas in the catchment upstream.

(ii) It's important to note that these scenarios are only likely to come into play during years when the river has temperatures well above average i.e. at the 5%ile upper range as measured at the stations, i.e. 22.8 at LRP and 22.3 at WOP. Even under these circumstances however it would seem unlikely that adult salmon migration would be halted at WOP due to the nature of the plume at that site and the greater dilution and lower ambient temperature there. This is because within the mixing zone, plume dispersal surveys for the site have always shown areas of cooler water (no more than 1-2 degrees above ambient) which would afford salmon a route for passage. Only in a short section at the downstream end of mixing zone (Chainage 750-1750m) is temperature in the range 2-3°C above ambient. At LRP, the possibility of delays in migration must be considered as thermal plume surveys at the site have shown that the zone where the channel joins the 'lagoon' at the head of Lough Ree generally experiences temperatures between 5°C and 7°C above ambient across the full channel during conditions of low flow.

(iii) In the case of LRP it is very unlikely that a delay in fish migration, were it to occur could have a significant adverse impact on the species population. Theoretically, any fish that were delayed in their upstream migration at LRP would potentially hold up at the deeper water in the lagoon which goes down to 7.5m or drop back down into Lough Ree and await a drop in temperature before continuing on their migration. This could potentially increase susceptibility of a migratory fish to cumulative temperature stress requiring it to find a cool enough refuge that would reduce its cumulative exposure. At a population level, it would seem very unlikely that delays to migration, were they to occur, could have a significant adverse impact for the following reasons:

(i) The frequency of occurrence of these events is likely to be very low, i.e. only occurring in very warm summers combined with low flow conditions.
(ii) Only a small portion of the population is ever likely to be affected, i.e. those fish that don't spawn in the lower catchment, where most of the wild stock are thought to spawn at present and of those only those that reach the power station locations in the warm period between late June and early August principally. Moreover, given that the river Suck joins the Shannon just above WOP and that the Inny joins the Shannon in Lough Ree it is clear that even fewer adults are likely to reach LRP, as a portion of these are likely to utilise the catchments of these two very extensive tributaries for spawning. This in turn means that an even smaller portion of the population is ever likely to be exposed to potential thermally-related migration delays. Clearly, all fish passing the power stations outside of the warmer months, autumn migrants, will not be affected as there is no potential for adverse impact from the thermal discharges at the lower temperatures recorded at these later times.

(iii) The current genetic profile of salmon in the river upstream of the Ardnacrusha dam emanates mainly from the Parteen hatchery stock, which is the source of large releases of smolts above the dam annually as well as an annual programme of unfed fry re-stocking in the mid to upper Shannon tributaries. Thus any periodic impairment of spawning success in a small number of adults due to thermally induced delays in migration will have no impact on the genetic make-up of the existing Shannon stock, which is currently artificially maintained.

Other Diadromous Species

The European eel is a eurythermal species and an examination of their thermal tolerances as part of the literature review indicated that this species is unlikely to be significantly adversely impacted by the presence of the thermal discharges with at most localised exclusion from the very warmest parts of the channel on the warmest months of the year. This conclusion is partly corroborated by the results of the 1st of 3 fyke net surveys for the species undertaken at 10 sites above and below both thermal discharge locations during August 2016. The survey recorded the species in nets both upstream and downstream of the thermal discharges at both sides of the river, at both stations, including in the discharge canal at LRP. Moreover, during the 2015 Trap & Transport programme for silver eels which is undertaken annually by the ESB, 58.5% of all the eels trapped (11.68 tons) were captured upstream of the WOP station at sites in Athlone, Roosky and Finea. 10% of the total were taken at Roosky (2tons), which was the single trapping site upstream of LRP. These data point to the ubiquitous distribution of the species within the Shannon catchment and the likelihood that the thermal discharges do not present any threat to the species. It is worth noting that eel throughout their European range are considered to be essentially a single panmictic stock so that the operation of the Shannon stations has no significance for the stock's genetics.

(4) *There was also no mention of pollan in the literature review, it is known that pollan do migrate out of the lakes on the Shannon, so it may also be worth including a small section on this species.*

The recent status of the Irish glacial relict *Coregonus autumnalis* has reviewed by Rosell et al, 2004 and the following very brief account is compiled mostly from that and a recent IFI paper on the 2014 status of Red Data fish species (O'Gorman *et al*., 2015). The Irish population, the only one in Western Europe and possibly a distinct sub-species or species, unlike it's Russian Arctic congeners is not anadromous being confined to a small number of lowland productive lakes including Lough Neagh, Lower Lough Erne, Lough Ree and Lough Neagh. More recently (2014) its presence has also been confirmed in Lough Allen by IFI surveys (O'Gorman *et al,* 2015) where there are encouraging signs of its population size. Historically the species may have occurred in other lakes also including Lough Derravaragh, Lough Iron, Upper Lough Erne and Lough Garradice. The species has declined considerably in all its current lake sites (although we don't have historical data for Lough Allen) and the Neagh population remains by far the greatest in terms of abundance. The Ree and Derg populations once at 5-9% of the fish population of those lakes has declined drastically to less than 1% of the fish population in recent years. Several hypotheses have been offered for the declines but a combination of increased eutrophication, competition from cyprinids such as roach and perch and most recently the introduction of invasive invertebrates, in particular zebra mussels, have all been implicated. Pollan spawn on the stony shorelines of Lough Neagh in December and are likely to spawn on the same substrate and around the same time in each of the other Irish lakes where it occurs also.

There are only very limited references to riverine occurrence of pollan but all those quoted in Rossel *et al.*'s, 2004, review appear to refer to the outfall of lakes i.e. the Shannon at Parteen/Killaloe, the Bann downstream of Lough Neagh and the estuary of Lower Lough Erne. The latter reference from Twomey (1956), indicated that the species sampled in that estuary in July were feeding almost exclusively on the estuarine crustacean *Crangon* and consequently showed scale markings indicative of improved growth as compared to growth rates in the Lower Erne. These occurrences may all be feeding-related, although the Lough Derg ones may have been entirely incidental as some at least tended to be associated with flood events. Clearly they were unrelated to reproduction because each population spawns separately on the lake shore. In the past, there may have been some genetic exchange between the stocks of the Shannon Lakes but there's no historical evidence of which I am aware to support this hypothesis. More detailed genetic studies on all the Irish stocks including Lough Allen may shed further light on this. It's very unlikely that the integrity of any of the current lake stock is dependent on genetic exchange for its survival, with the environmental and biotic threats likely to be much more decisive for the Irish sub-populations.

The upper thermal limit of the specie is variously put at 20-22°C (see Anon 2005) confirming that this is a cold-water species. Recent (2014) survey of Lough Ree (Kelly *et al*., 2014) has indicated that the species is confined to the deeper parts of the lower half to one third of Lough Ree which is well beyond the thermal influence of LRP. Furthermore, none of the likely spawning sites on the lake are affected by the discharge, especially as spawning takes place in the winter when the extent of the LRP plume is at its most confined. For all the same reasons, the WOP thermal discharge it not believed to be having any possible adverse impact on the pollan stocks of Lough Derg.

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Adult Salmon Migration on the Shannon – Overview of Trends and Numbers

The Ardnacrusha hydro station and Parteen Regulating Weir both came into full operation in 1929 regulating the upward migration of salmon to the large portion of the Shannon catchment upstream of these structures. In 1959 returning adult salmon numbers began to be recorded for the first time at Parteen Weir as part of the hatchery and re-stocking programme initiated there at that time. The salmon were and still are counted as they enter adult traps and are either removed to the river immediately upstream of the trap or retained as hatchery broodstock for stripping of eggs and milt. At the same time a Borland fish pass (or fish lift) was installed at Ardnacrusha hydrostation which also allowed a census of the fish passing upstream. The results of these counts were supplied by Dr Denis Doherty ESB Fisheries Conservation and are presented in Figure 1 along with the commercial salmon catches since 1940 at Thomond Weir situated just upstream of Limerick City centre but downstream of the dam and also downstream of the confluence of the Mulkear River, an important salmon spawning river on the lower Shannon. It is assumed that had they not been taken in the commercial fishery the majority of the salmon captured at Thomond Weir would have made their way into the Mulkear River main Shannon catchment above the dam via Parteen Weir and also via Ardnacrusha after 1959 with the installation of the Borland lift. They would also have included 'stray' fish from other rivers lower down in the system e.g. the Maigue and the Feale.

These data are presented in order to show the recent historical trend in adult salmon numbers returning to the Shannon and in particular to highlight the dramatic decline in those numbers since the 1960's when the highest numbers were recorded. Figure 2 extracts the total numbers (including those for Thomond Weir) from 1971 to 2017 displayed as a 5-year running average along with the numbers of returning adult 1-sea winter fish (grilse) for the southern area of the NE Atlantic i.e. fish returning to Irish UK and French rivers in particular, extracted from Chaput (2012) and also presented as a 5-yr running average. These latter data show clearly that the trends on the Shannon are part of a much wider decline in returning salmon numbers in the region which has been attributed to a decline in sea survival rates among other factors. In the case of the Shannon salmon there seems to have been a similar decline to that of the region from 1971 to 1980, followed by a more precipitous decline than in the region between 1980 and 1990 with a similar and more or less levelling trend since about 2000, when the Shannon numbers have been around 2000 or less on average

It is also worth noting that recent genetic studies on all the existing Shannon salmon stocks and on scales from fish caught and archived before the construction of the dam, indicates that all extant populations are from the rivers discharging below the dam or from the hatchery stock at Parteen, which are themselves derived from the lower Shannon tributary stocks. Thus the native 'above-dam' Shannon stock no longer exist (pers comm Dr Philip McGinnity). There used to be a very significant run of large multi sea-winter salmon in the Shannon, however, these have gradually declined since the construction of the dam and the vast bulk of returns are now either hatchery origin grilse or 2 SW salmon.

Salmon migrate upstream through the Borland fish lift in the Ardnacrusha dam or via the fish pass located at Parteen weir in every month of the year. However, the numbers vary considerably from month to month. Figure 3 and Tables 1 and 2 present the data for the most recent years (2013 to 2017) which clearly shows that the runs are concentrated into 2 periods namely summer (June & July mainly) and autumn/winter (October and November mainly). These details are relevant when we come to consider the issue of the potential impact of the thermal plume acting as a migratory barrier on these fish. Virtually all of the returning fish are either hatchery reared fish (~45%) or 'wild' fish (~55%) which are fish that are the progeny of returning hatchery adults spawned upstream or downstream of the dam that are themselves the progeny of hatchery reared smolts . The native salmon stock that historically occurred upstream of Ardnacrusha, no longer exist.

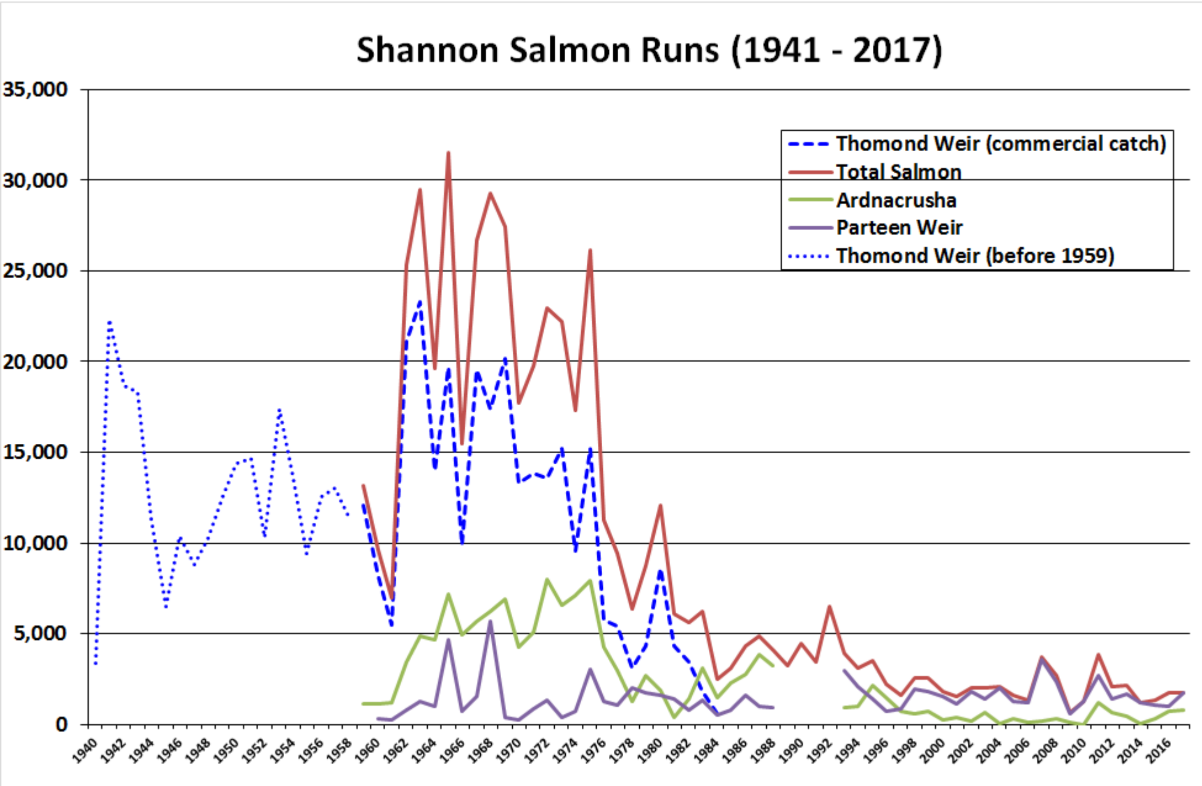

Figure 1 Recent historical trends in returning adult salmon - River Shannon (see text for more details. (data from Dr Denis Doherty ESB Fisheries)

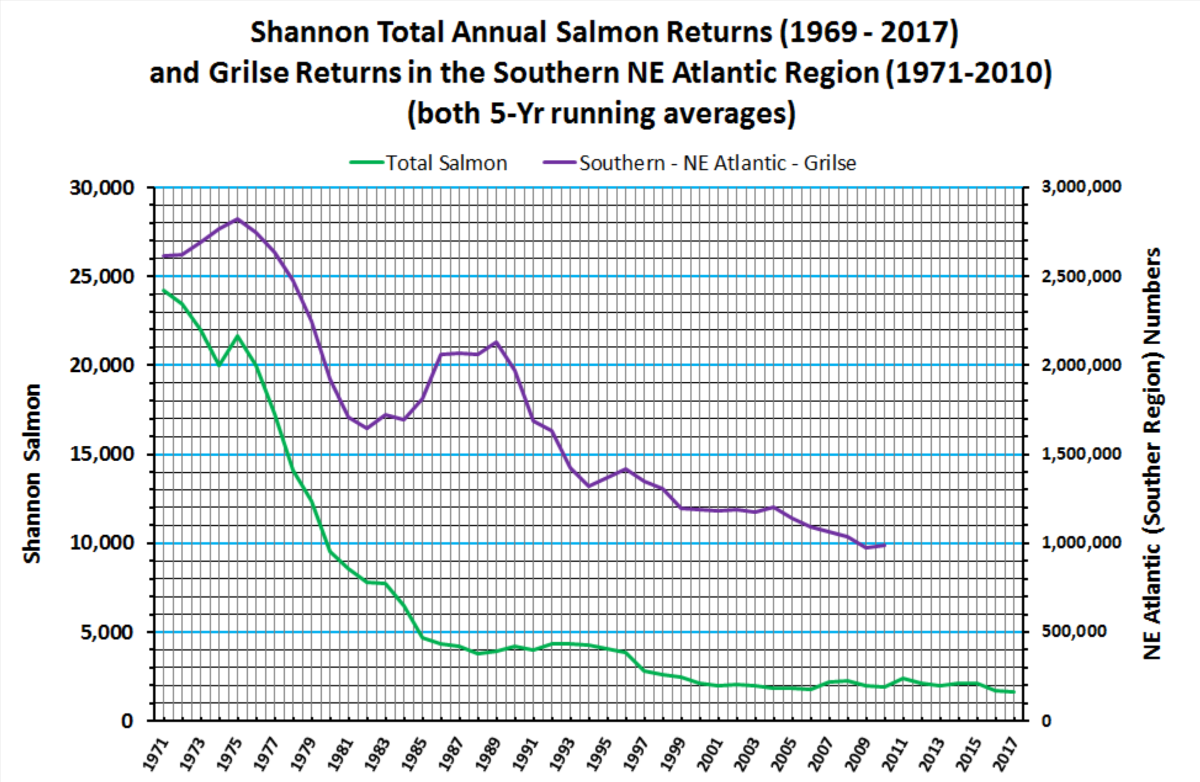

Figure 2 Shannon total salmon numbers compared to regional Atlantic salmon returns (1971-2017)

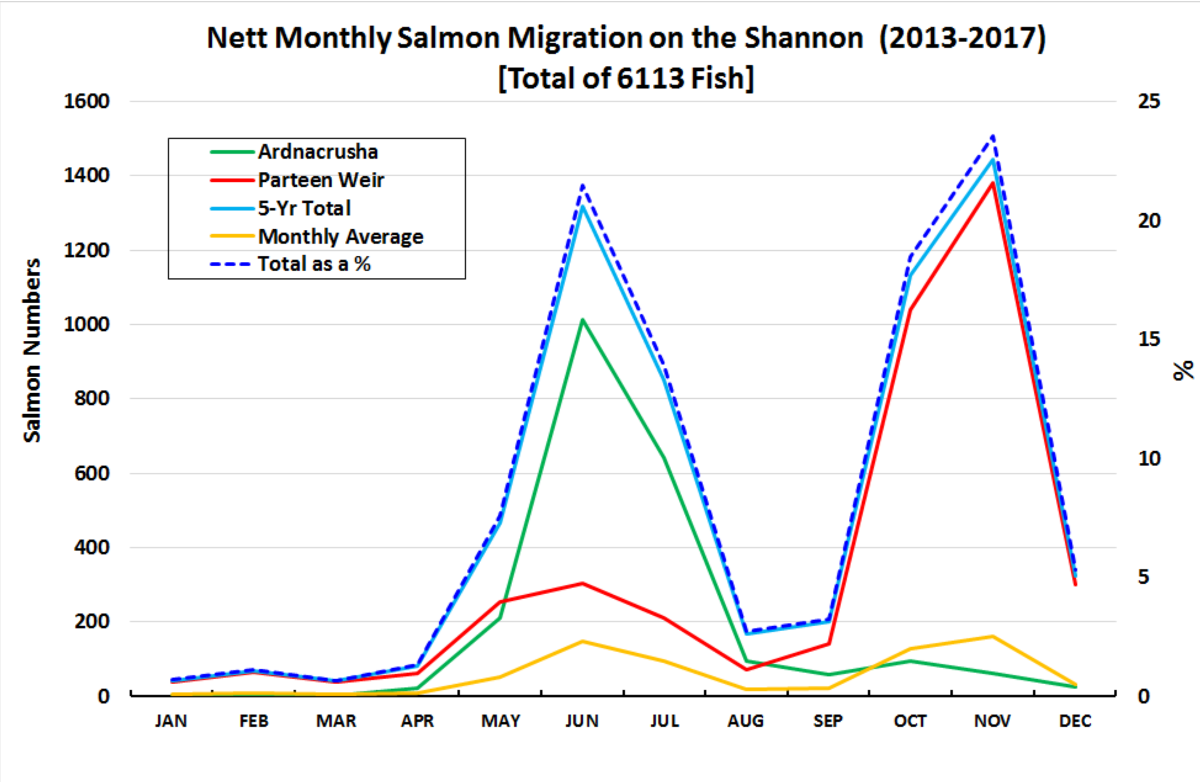

Figure 3 Monthly adult inward migration on the Shannon for the period 2013-2017 (data D. Doherty

	2013		2014		2015		2016		2017	
	Ard	Part	Ard	Part	Ard	Part	Ard	Part	Ard	Part
JAN	2			0	0	0	1	38	0	1
FEB	2	1		0	0	1	3	62	0	0
MAR	0	5		18	0	-1	1	17	0	0
APR	13	9		27	7	0	1	24	0	0
MAY	39	155		75	2	8	157	16	14	0
JUN	77	84		31	181	100	424	88	332	0
JUL	62	91		23	118	97	109	0	352	0
AUG	21	21		4	46	30	19	16	9	0
SEP	44	31	10	16	0	54	3	39	2	0
OCT	22	115	11		1	325	7	86	53	513
NOV	34	112	1	0		399	1	483	26	387
DEC	12	81	0	0	0	20	12	139	0	60
TOTALS	**328**	**705**	**22**	**194**	**355**	**1033**	**738**	**1008**	**788**	**961**

Table 1 Monthly numbers of adult salmon migrating via Ardnacrusha and Parteen Weir (2013-2017)

%	Ardnacrusha	Parteen	Total	% of Total
JAN	3	39	42	0.7
FEB	5	64	69	1.1
MAR	1	39	40	0.7
APR	21	60	81	1.3
MAY	212	254	466	7.6
JUN	1014	303	1317	21.5
JUL	641	211	852	13.9
AUG	95	71	166	2.7
SEP	59	140	199	3.2
OCT	94	1039	1133	18.5
NOV	62	1381	1443	23.5
DEC	24	300	324	5.3

Table 2 Monthly totals of migration salmon (2013-2017) with the % contribution for each month

Temperature Tolerance of Atlantic and Implications for Migration Past LRP

Atlantic salmon is the most tolerant of elevated temperatures of all salmonid fish. Detailed temperature tolerance assessments undertaken by several authors have come up with the following key temperature tolerance figures for juveniles of the species (mainly 0+ and 1+) fish Table3:

Temperature	Temperature Type	Significance
32.81°C (acclimation temperature 15°C or 20°C) Elliot & Elliot (1995)	CT max Critical Temperature (maximum)	The temperature a fish can tolerate for very short periods of exposure (~10minutes) before reaching an end point, i.e. loss of equilibrium followed immediately by death. If returned to cooler (acclimated) temperatures within this period the fish will immediately recover.
27.51°C acclimation temperature (20°C) Elliot & Elliot (1995)	IULT (Incipient Upper Lethal Temperature)	Temperature that can be tolerated by 50% of a population for extended periods of exposure (~7days) during which (toward the latter end of the 7 days) fish (up to 50%) will begin to die if not removed to cooler temperatures).
29.5°C (acclimation temperature 20°C) Elliot 1991		Temperature at which parr can survive for up to 16.5 hours (Elliot 1991)
31.1°C acclimation temperature 20°C) Elliot 1991		Temperature at which parr can survive for up to 1.6 hours (Elliot 1991)

Table 3 Critical maximum temperature limits for Atlantic salmon

Another feature of temperature tolerance in this species is that it has been demonstrated to be independent of the geographical distribution of populations, i.e. it is just as applicable to salmon from northern Norway as it would be for population in France provided both are initially acclimated to the same temperature (see Anttila et al, 2014).

The tolerance limits presented in Table 3, were established using fish under laboratory conditions and corroborated by more than one author. However, recent research has shown that Atlantic salmon parr also occur naturally in watercourses where temperatures can not infrequently reach these ranges. Dugdale *et al,* (2016), studying the movement of Atlantic salmon parr in a Canadian river used PIT tags to follow the movements of parr seeking refuge from high temperature main stem sites into cooler tributaries as temperatures rose. The study noted that temperature-related movements in the main stem of the river occurred during a 28-day period in July/August when the average temperature was 23.2°C +/- 3°C and the maximum was 30.5°C. When assessing data for the movement of fish from the main stem into cooler tributaries, the authors found that the best predictors of movement was average main-stem temperatures greater than 22°C for extended periods and temperatures of 28°C for shorter periods. In the case of the lower temperature 50% of movements were predicted to occur after 61 hours exposure and for the higher temperature 50% of movements were predicted to occur after just 1.5hrs of exposure. I have used the results of these field studies, informed also by the temperature tolerance values for Atlantic salmon in Table 4 as a guide to analysing the possible impact of the thermal plumes on adult salmon migration in the Shannon at WOP.

I have made the assumption that salmon encountering temperatures at or lower than 22°C within the zone of influence of the thermal discharge will not be deflected in any way by it. Above this temperature, the likelihood that a salmon might be forced to halt its migration will depend on (i) the temperature involved and (ii) the duration of exposure. In the following table therefore I have analysed all those continuous temperature monitoring reporting period from July 2016 to December 2017 where temperatures were found to be at or above 22°C and calculated (i) the full period over which that occurred and (ii) the duration of sub-periods within that whole for each subsequent 1 degree rise in temperature. Furthermore, within this overall body of data, only sites with the coolest temperatures of the channel were assessed i.e. temperature logging sites S2 and S3 or site S5, S6 and S7 depending which had the coolest temperatures at the time, as it was assumed that salmon would choose to take the coolest route at any given time. In addition, it was assumed that salmon would avoid the higher temperature surface waters and travel deeper in the water column where the coolest temperatures were consistently encountered and therefore only data for the deeper (1.5m) logging stations at each of the chosen sites were analysed.

From temperature logging site S7, downstream, to a point upstream, where the surface temperature is less than 0.5°C above ambient is just 1.5km and at depth it's just 1km. Thus a [1]70cm salmon travelling at 1 body length per second, which has been shown to be an energy efficient cruising speed for salmon (Quinn, 1988), would take just 36 minutes in zero current to cover this distance. If we assume that the salmon is swimming against a current of around 0.25 m/s then its ground speed would be reduced to about 0.45m/s and it would take about 56 minutes to cover the 1.5km distance. Thus in this analysis a migrating adult salmon would be potentially exposed to temperatures at or in excess of 22°C for this short time. Based on Dugdale *et al.,* (2016) at the lower temperature of 22°C salmon would have to be continuously exposed to this temperature for as much as 61 hours before there was a 50% likelihood of their seeking out a cooler refuge. By the time the temperature had reached 28°C, however, that exposure time would have dropped to just 1.5hrs before there was a roughly similar likelihood that the salmon would seek cooler waters. Bearing this in mind and the fact that the salmon is more than likely homing to an upstream spawning site and therefore motivated to continue upstream, temperatures would need to be at the higher end of this 22 – 28°C range before there would be a significant likelihood that a fish would discontinue its migration to seek a cooler water refuge, given the very short exposure time we are likely to be dealing with. In order to use these data in a practical scheme to assess the likelihood of an interruption to migration, I have used a traffic lights colour scheme in Table 4 to interpret the data presented in Table 5 with the assumptions underlying the % of the population at risk deduced from a consideration of the evidence presented above:

[1] The average length of Shannon grilse

>22<24°C	No interruption to migration
>24<26°C	<25% of population affected
>26<27°C	>25 <50% potentially affected
>27°C	>50% potentially affected

Table 4 Temperature categories and putative impacts on salmon migration subject to short exposure times in each temperature interval (see text for explanation)

WOP

April - May 2017				
Apr 27 - May 30	**33 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
S2 (1.5m)	>22 <23°C	2	0.17	0.02
	All >22°C	2	0.17	0.02
S3 (1.5m)	All >22°C	0	0	0
Ambient Temp (S1)				
Average (°C)	14.8			
Maximum (°C)	18.1			
WOP				
May-June				
May 30 - Jun 27	**28 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
S2 (1.5m)	>23 <24°C	213	17.8	2.6
	>22 <23°C	496	41.3	6.2
	All >22°C	709	59.1	8.8
S3 (1.5m)				
	>23<24°C	17	1.4	0.2
	>22 <23°C	841	70.1	10.4
	All >22°C	858	71.5	10.6
Ambient Temp (S1)				
Average (°C)	17.4			
Maximum (°C)	21.3			

Table 5 Temperature intervals at and above 22°C recorded at L4 and L6 at LRP between July 2016 and December 2017

WOP

June - August 2017				
Jun 26 - Aug 27	**57 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
Site S5 (1.5m)	>23 <24°C	5	0.42	0.03
	>22 <23°C	263	21.9	1.61
	All >22°C	257	21.4	1.57
Site S6 (1.5m)				
	>23 <24°C	6	0.50	0.04
	>22 <23°C	45	3.75	0.27
	All >22°C	52	4.33	0.32
Site S7 (1.5m)				
	>22 <23°C	124	10.33	0.76
	All >22°C	124	10.33	0.76
Ambient Temp (S1)				
Average (°C)		17.7		
Maximum (°C)		20.0		

Table 5 Contd:

When examining the data in Table 2, it is important to note that the 4th column presenting 'Duration (Hours)' refers to the total time during that recording period for which a particular temperature range lasted, it DOES NOT refer to the exposure time of a migrating salmon to elevated temperatures, which we have earlier estimated to be just under 1 hour.

In all there were just 3 reporting periods when temperatures exceeded 22°C at depth i.e. April-May 2017, May-June 2017 and June-August 2017. However, given that all these temperatures remained below 24°C at all times, and that the maximum exposure for any given fish was likely to not exceed 1 hour, it can be concluded that no fish was likely to have delayed their upstream passage due to the temperatures encountered at WOP at any stage from July 2016 to December 2017, which included a summer (2017) that had lower than average flows at this site.

The other life stage that might be affected by the thermal discharges at WOP are seaward migrating smolts. The ESB operate a 'smolt protocol' at the dam at Ardnacrusha between mid-March (i.e. once the river temperature rises to around 8°C to 10°) continuing to around mid-June. This is a power generation procedure using a Kaplan Turbine which is designed to facilitate the movement of smolts down past the dam with minimal mortality rates rather than have them delayed just above it. According to Denis Doherty ESB Fisheries Conservation, the duration of the smolt run varies quite a bit from year to year. Depending on whether the year is cooler or warmer the run might begin later or earlier, be of short and fairly concentrated duration or extended in a stop-start fashion. The latter will also be influenced by discharge which research has shown is probably the most important factor affecting the rate of seaward migration. It usually stops in any case once water temperatures reach 18°C.

Smolts are likely to have a similar upper thermal tolerance limit to adult salmon. Under ambient conditions smolts are never exposed to these temperatures at WOP but in exceptionally warm years, late running smolts i.e. in late May or early June could in theory be exposed to these levels in the plume. Against that, in warmer years one would expect that the bulk if not all the smolts would have already migrated, given cessation of the run at Ardnacrusha observed to generally coincide with a warming to 18°C as cited above. Combining this with the trend for smolts from tributaries farther upstream in a catchment to commence their seaward migration earlier than smolts closer to the sea, as shown by Stewart et *al.,* (2006) for the River Tay in Scotland and supported by evidence from New England showing smolts from sub-catchments farther from the sea developing smolt physiological characteristics as they migrate downstream (McCormick *et al.,* 1999), would suggest that the likelihood of any significant number of fish being exposed to this temperature level in the discharge plume is relatively remote. However it cannot be ruled out entirely and in this scenario a more significant impact of the discharges however could relate to the rate of passage of smolts in warmer years and how elevated temperatures impair the swimming speed of smolts. In tank-based experiments, Martin *et al.,(*2012) found the optimum swimming speed of Atlantic salmon smolts to be 13°C and that above 17°C this rate was reduced by up to 80%, while at 20°C smolts stopped swimming. This would suggest that smolts appear to be more susceptible to elevated temperature-related impacts on their swimming speed than parr, which have been shown to be active in the wild at temperatures above 22°C or more (Dugdale *et al.,* 2016). According to the 10-year temperature record (2006-2016) for the WOP cooling water intake, the maximum ambient temperature in May was 19.05°C while the 5%ile temperature was significantly lower at 16.74°C (see Tables 3a & 3b and Figures 2a & 2b in ASU 2016). These temperatures are not encountered in March in the discharge plume and tend to be the exception in April, but occur regularly in May and are the rule in June at WOP (see Tables 3b, in ASU 2016). We know from the 2016 thermal plume surveys undertaken on April 29th 2016 that the plume at WOP was closely confined to the eastern side of the main channel, with no impact on the western side of the channel. This means in effect that smolts could have travelled down past the plume along the cooler western side of the channel where the temperatures were at ambient and where they would have been be unaffected by the thermal discharge. Even on the plume side of the river the highest surface (0.3m) temperature was just less than 16°C at the time. In contrast to the 2016 findings, in the May 2017 continuous monitoring was undertaken during lower flows and temperatures in excess of 20°C occurred at S2 (1.5m) for a total of 5.4 days and S3 (1.5m) for a total of 2.2 days. In both cases all recordings >20°C occurred during the final 6 days of the month. In these situations, if the swimming impairment noted in laboratory studies (Martin *et al*., 2012) translated exactly to the wild then the smolts would drift rather than actively swim that stretch. This would in theory at least expose them to a greater risk of predation by pike resident in the affected reaches and perhaps also to avian predators if the smolts were migrating during daylight hours.

Another risk of elevated temperatures to smolts relates to the physiological changes associated with the process of smoltification which prepare them for entry into a marine environment, where elevated temperatures tend to slow or reverse this process. However, McCormick *et al.,* (1999) have indicated that this is a cumulative effect measured in degree days and the effect may not be significant for such a short passage (1-1.5km) at WOP when viewed in context of the further 78km that the smolts would have to travel to get to the dam at Ardnacrusha.

It is clear from the foregoing that in some years, with low flows in May that a certain portion of the smolt population migrating from tributaries upstream of WOP may be exposed to an increased risk of predation and a small increase in accumulated thermal stress over a 1-1.5km stretch of the river downstream of WOP. In the absence of more precise knowledge of the timing of the smolt run in this part of the catchment (which will vary from year to year), or of the numbers involved, it is difficult to quantify the impact on smolts. However, it is reasonable to assume that the effect is more likely to be minor than moderate because (i) only in certain years would the flows be low enough at that time of the year to see the plume reach to the right (western side) of the channel (ii), the fact that the bulk of smolts may already have started their seaward migration by May that far upstream in the catchment and (iii) the relatively short distance over which the effect would persist.

Summary & Conclusion

Over the past 40-50 years there has been a dramatic decline in the numbers of salmon returning to rivers on both sides of the north Atlantic and that is reflected also in the ESB's records for salmon on the River Shannon. Furthermore, the number reaching the West Offaly Power Station in Shannonbridge, some 78km upstream of the Ardnacrusha hydro station, is likely to be only a small proportion of the on-average 2000 or fewer salmon that return on an annual basis currently, as the majority enter tributaries farther downstream to spawn. Records available for recent years suggest that on average about 35% of all the salmon that escape into the system upstream of the dam do so in the months of June and July and it is likely that only a portion of these salmon are likely to encounter temperatures at WOP that could delay their upstream migration. Indeed, an analysis of the continuous temperature data for this period in 2017, would suggest that in 2017 none of the salmon reaching the WOP reach would have been delayed in their upriver migration. This assumption is based on a review of the published literature on the species thermal tolerance both in the field and in laboratory studies and the assumption that migrating salmon would choose to follow the coolest track through the temperature-affected reach at WOP.

Returning smolts could be at some risk, although one that is less easy to quantify due to the absence of data on the numbers likely to be migrating down through the WOP section of the river. It is believed that in most years by the time temperatures would be high enough to cause the smolts temperature-related difficulty, namely in the form of impaired swimming performance, most of the population would likely have already migrated past this point in the river. Moreover, the significant distance of the site from the sea might also mean that the majority of the smolts would have started to migrate before May, when the 2017 temperature record showed that there were short periods when temperatures were high enough (i.e. ~20°C) to reduce the swimming ability of smolts at WOP, thereby slowing their passage through the affected ~1-1.5km of river, which in turn might make them more susceptible to predation by pike or perhaps avian predators also. Overall, taking into account the available data on temperature for the site as well as its location, it is considered that the risk to smolts due to the WOP thermal discharge is more likely to be on minor than a moderate scale at the population level.

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